Implementation of a Manufacturing Technology Roadmapping Initiative

by

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SUBMITTED TO THE MIT SLOAN SCHOOL OF MANAGEMENT AND DEPARTMENT OF MECHANICAL ENGINEERING IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREES OF

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Abstract

Strategic technology planning is a core competency of companies using technological capabilities for competitive advantage. It is also a competency with which many large companies struggle due to the cross-functional knowledge that needs to be shared, the varying perspectives that must to be aligned, the complicated network of dependencies that need to be understood and the high-degree of uncertainty involved in technology planning. Technology roadmapping has proven to be an effective strategic technology planning technique that can overcome these challenges.

This thesis reviews literature on technology roadmapping and expands on this literature by applying these techniques to roadmapping the manufacturing technology. While the existing literature largely focuses on roadmapping the technologies that will directly deliver value to the customers, this thesis focuses on the technologies that indirectly deliver value to the customer. In an advanced products company, examples of the former and latter technologies are the product and manufacturing technologies, respectively. This distinction has important implications for the management of these technologies.

Technology roadmapping is a powerful and flexible technique that must be tailored to the strategic context where it will be implemented. Through a case study of the development and implementation of manufacturing technology roadmapping at Raytheon Space and Airborne systems, the author seeks to provide a general set of guidelines for roadmapping a company's technology that indirectly add value to the customer.

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1 Introduction

1.1 Motivation

Strategic technology management is the single greatest challenge facing advanced technology companies today (Scott, 1998). The challenge is understanding how to determine what technologies should be developed in order to achieve the company's business objectives. Effective technology management is a critical capability for advanced technology companies, as these companies invest a significant portion of their earnings into developing new technologies. Developing and deploying a technology management strategy provides the vision to align the development of new technological capabilities with the business objectives.

Raytheon Corporation has a rich history of developing state-of-the-art technologies, delivering its customers with some of the most advanced capabilities in the world. Producing these technologically advanced products often pushes the boundaries of existing manufacturing capabilities, necessitating the development and acquisition of advanced manufacturing technologies. Creating a strategic plan for the development of new technologies is a challenging endeavor that is complicated by the uncertainties inherent in the development of new technologies. These uncertainties pertain to both, the product technologies that are delivered to the customer and the manufacturing technologies that produce the products. Successfully developing and exploiting advanced technologies takes a significant amount of resources and time, and an effective strategic planning process is important for ensuring that the new technologies will satisfy the business objectives.

The Department of Defense (DoD), Raytheon's largest customer, has placed renewed emphasis on the manufacturing readiness of defense acquisition programs, citing this as a major cause of cost overages and schedule slip (OSD Manufacturing Technology Program, 2011). As Raytheon's customers continue to demand the development of ever-advancing technologies in shorter timeframes, the importance of developing and implementing a process to ensure the manufacturing capabilities are developed and available for production is also increasing.

The motivation of this project is to develop and implement a strategic planning process at Raytheon Space and Airborne Systems (SAS), a business of the Raytheon Corporation, to improve the allocation of resources for the development and acquisition of advanced manufacturing technologies. The planning process will ensure manufacturing technologies are "production-ready" when needed and that the core manufacturing capabilities are developed.

1.2 Research Goals

This thesis is based on work conducted on-site at Raytheon Space and Airborne Systems (SAS) in El Segundo, CA from February through July 2011. Louis Grillon continued the roadmapping project, expanding on this work and advancing the roadmapping initiative at Raytheon SAS. Both projects were performed as part of an internship through MIT's Leaders for Global Operations program. The goal of this project is to develop and implement a manufacturing technology roadmapping process that will provide the strategic vision for the manufacturing technology and guide the investment decision-making process. This strategic technology management capability will enable Raytheon SAS to effectively allocate resources for the development of advanced manufacturing capabilities, ensuring the technologies are "production-ready" when needed to deliver products to its customers and continue to win new business.

The author seeks to not only develop and implement a manufacturing technology roadmapping process at Raytheon SAS, but seeks to leverage the research and experience gained to develop a set of general guidelines for developing and implementing roadmapping processes at other companies. While there is an abundance of literature on technology roadmapping, the author's intent is to expand on the literature by focusing on the application of roadmapping for manufacturing technology, for which very little literature exists, and particularly on the initiation of roadmapping and the development of the first roadmaps. The author will incorporate thoughts from literature on technology roadmapping, strategic management, new product development, change management, organizational processes, system dynamics and leadership in order to provide an accurate understanding of the challenges and success factors for developing and implementing a roadmapping initiative at a large advanced technology company.

Roadmapping is a powerful and flexible technique that must be developed and tailored for the environment in which it will be implemented. The goal of this thesis is to provide insight into, and a general set of guidelines for the development and implementation of a roadmapping initiative. The goal of this project is to kick-off a manufacturing technology roadmapping initiative at Raytheon SAS that will provide a strong foundation of knowledge and support for the long-term success of the initiative. At the conclusion of this project, Louis Grillon continued the implementation, focusing on the integration and sustainment of the initiative.

1.3 Outline of Thesis

The goal of this thesis is to provide the reader with insight into the challenges and success factors for initiating manufacturing technology roadmapping and developing roadmaps. Chapter Two provides an overview of strategic technology management and technology roadmapping, highlighting the best practices, success factors and challenges found in the literature. Chapter Three provides background information on Raytheon SAS and the defense industry relevant to this project. Chapter Four sets the stage for the roadmapping initiative and discusses the importance of understanding the strategic context for the initiative and building leadership support. It concludes by defining the scope and objectives for the manufacturing technology roadmapping initiative. Chapter Five discusses the process of designing the architecture for the roadmaps and proposes a roadmap architecture for Raytheon SAS. Chapter Six discusses the development of a roadmapping process and the important considerations. The chapter concludes with a proposed roadmapping process for the first iteration of roadmapping. Chapter Seven discusses the execution of the roadmapping process and the development of the first roadmaps. This chapter will discuss the author's findings from executing the roadmapping process and proposes a revised process for future roadmapping iterations. Chapter Eight concludes the thesis by providing key findings and recommendations for future roadmapping initiatives.

2 Technology Management

Technology management refers to the set of practices for managing the technological capabilities that provide the company with a competitive advantage in the market. Technological capabilities broadly include any technologies that a company incorporates into the products delivered to customers or that enable a company to develop, produce and deliver those products. The European Institute of Technology and Innovation Management (EITIM) defines technology management as:

> Technology management addresses the effective identification, selection, acquisition, development, exploitation and protection (product, process and infrastructural) needed to maintain a market position and business performance in accordance with the company's objectives.

This definition highlights the importance of the linkage between the technological and business objectives. In other words, the goal of technology management is to ensure the technology and business strategies are aligned and synergistic in order to accomplish the company's objectives.

In this chapter, we will provide a brief overview of an integrated technology management framework, highlighting the different stages and tools of technology management. Next, we will focus on technology roadmapping as a tool of technology management, discussing both the product (i.e., the roadmaps) and the process of roadmapping. Finally, we will conclude the chapter with a discussion of the success factors and challenges of implementing technology roadmapping within a company.

2.1 Technology Management Framework

Foden and Berends (2010) propose an integrated technology management framework for the manufacturing technology at Rolls-Royce, which will be adopted for the purposes of this paper. The framework is divided into six stages, similar to the EITIM definition of technology management. The main intent of each stage and some of the appropriate tools are discussed below. Figure 1 illustrates the proposed framework and Figure 2 lists the tools for each stage of technology management.

Identification and Monitoring provides the company with an understanding of the internal and external technological environment. The purpose of this stage is to maintain awareness of technology developments that provide opportunities for achieving business objectives. Benchmarking and technology maturity assessments are two of the more common tools used for these purposes.

Selection and Approval seeks to identify those technology opportunities identified in the previous stage that satisfy business objectives and provide good investment opportunities. This stage serves two main purposes: 1) consolidation of technology ideas and 2) alignment of technology and business strategies to enable technology investment decision-making. Technology roadmapping is a technology management tool for this stage that aligns technology opportunities with the market and product drivers, providing insight into the best investment opportunities.

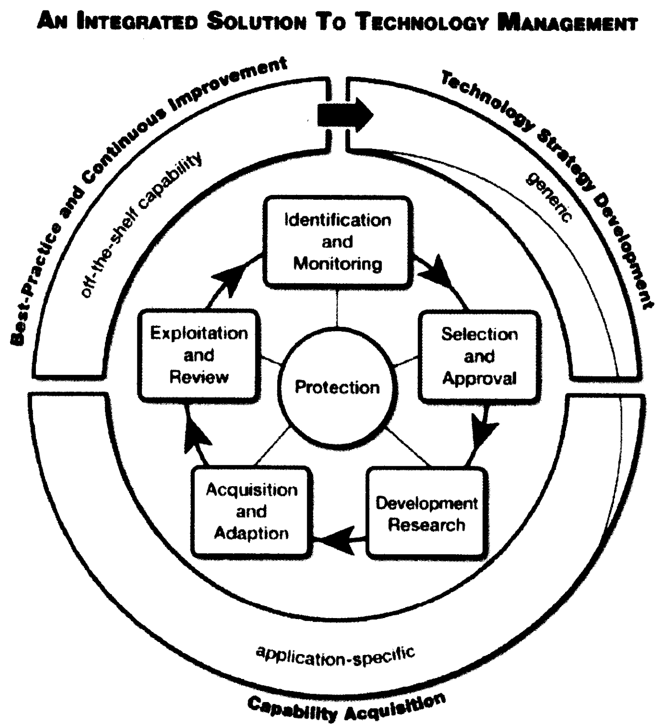

Figure 1: Integrates Solution to Technology Management (Foden & Berends, 2010)

Development Research is the stage where the technologies selected and approved in the previous stage are matured and their capability is proven.

Acquisition and Adaptation prepares the technology for use in the actual environment. For manufacturing technologies, this means that the technology is matured and adapted to the meet the production requirements. For a product technology, the technology is developed to be ready for incorporation into the products.

Exploitation and Review is the time when the technologies are deployed as an off-the-shelf capability. Further improvements in the technology focus on continuous improvement. Over time, the technologies are monitored by the Identification and Monitoring stage to determine when the technology is no longer satisfying the requirements and a new technology is needed to replace the existing technology. This completes the serial stages of the technology management framework.

Protection is the sixth stage and works together with the other five stages to protect the technology. The purpose of this stage is to appropriately protect the technological capability, through intellectual property, trade secrets, and/or risk management.

Framework Stage	Tool	Description
Identification and Monitoring	Technology Networking	Exploratory tool for increasing external environment awareness through participant networking.
	Technology Watch	Identification of organization's critical established, competing and disruptive technologies.
	Make-the-Future	Inward-facing technology opportunity identification aligned with product development programs.
	Technology Maturity Assessment	The assessment of the position of a technology's maturity along its S-curve/life cycle.
	Technology Benchmarking	Internal benchmarking of technology alternatives with the organization + benchmarking against competitors.
Selection and Approval	Make-the-Future Selection	Inward-facing technology opportunity down-selection aligned to new product drivers.
	Technology Roadmapping	Convergence of inward and outward-technology opportunities aligned to market and product drivers to enable selection of R&D programs.
	R&T Funding Approval	Technology investment decision-making for technology opportunities presented by Technology Roadmapping.
Capability Development: Development Research, Acquisition & Adaptation, and Exploitation & Review stages	Technology Make-Buy	Make or buy decision-making for development of down- selected technology program capabilities.
	Capability Acquisition	Definition, launch and management of technology programs aimed at developing technology maturity through R&D.
	Technology Readiness Scale	A gated process against which current technology maturity can be gauged and managed.
Protection	Technology Risk Management Knowledge Base Protection Intellectual Property (IP) Protection	Management of risks arising from R&D technology programs. Capture of valuable knowledge such that it can be re-used. Protection against unauthorized transfer of IP outside of the organization.
*Development Research, Acquisition and Adaptation, and Exploitation and Review stages have been absorbed into an overarching Capability Development stage for the purpose of simplification.		

Figure 2: Tools for Each Stage of Technology Management (Foden & Berends, 2010)

Foden and Berends discuss the importance of establishing an overarching framework to integrate the many activities of technology management. They suggest three dimensions of integration 1) inputs and outputs of the tools, 2) organization and ownership and 3) timing. The tools should complement one another, with outputs from one stage being the inputs for the next stage to create a flow of information through the technology management process. Clear organization and ownership of each activity is especially important in large complex organizations to ensure each activity is completed with the overall objectives in mind. Finally, the timing is important to ensure the technologies are ready for use when they are required.

The integrated technology management framework has been tested with promising results for companies seeking a competitive advantage through its core manufacturing capabilities. Establishing an overarching framework that is robust, systematic and transparent is critical for effective technology management.

Although we will focus on the Selection and Approval stage for the remainder of this paper, particularly on technology roadmapping as a tool, it is useful to keep the entire technology management framework in mind.

2.2 Technology Roadmapping

Roadmapping, in its most general sense, is a form of strategic planning whereby a group of stakeholders collectively map the path to the future. Roadmaps, the product of the roadmapping process, are shared representations of this vision. Roadmapping seeks to answer the following questions:

- Current State: Where are we today?
- Future State: Where do we want to be in the future?
- Closing the Gap: How do we get from the current state to the future state?

Roadmapping is especially useful when the answers to these questions are not obvious. Reasons that the answer is not clear include, the solution requires the input of several stakeholders across different functional and business units, the information is interconnected and uncertain, and the dependencies between the information is not well understood. Roadmapping provides a means to gather and synthesize a complicated network of information, dependencies and stakeholder perspectives to develop a common strategic vision for the future. Technology roadmapping is a tool to strategically align a company's technology and business strategies by **1) linking technological capabilities to business objectives, 2) identifying and prioritizing critical technology gaps, 3) setting targets and action plans, and 4) facilitating communication across the organization.**

The University of Nottingham Strategic Technology Alignment Subgroup (part of Nottingham's Responsive Manufacturing Group) provides a "working definition" of enterprise-level technology roadmapping as:

> A methodology to optimize the acquisition and alignment of technology, in order to enhance the achievement of strategic goals and minimize the risk of technology-based disruption (Gindy, Cerit, & Hodgson, 2006).

Scott (1998) conducted a survey of 63 participants from product companies, R&D laboratories and academia that identified "strategic planning for technology products" as the single most critical challenge facing today's organizations. Follow-on surveys indicate that linking the business and technology strategies is the single most important sub-issue under the strategic planning of technology products. Also in the top ten most urgent issues is the planning for technical core competencies and the integration of technology strategic planning (Scott, 2001). Technology roadmapping has proven to be an effective technique for addressing these issues.

2.2.1 The Product

Technology roadmaps are the product of the roadmapping process and reflect the collective perspective of the various stakeholders. The roadmap is a shared representation created by the stakeholders that can be used to develop and communicate the strategic vision.

There are several different types of roadmaps, both in the purpose that they serve and in the format that they take. The most common type of company-level roadmap is a time-based illustration with multiple layers, each containing a different type of information, such as markets, business objectives, products, technologies or resources. Phaal, Farrukh and Probert (2004) propose a generalized roadmap architecture, shown in Figure 3. Time is shown on the horizontal axis and the vertical axis contains the layers. The top layers present the commercial purpose that is driving need for the roadmap (the 'know-why'). The bottom layers contain the technological resources that will be deployed to address the top layers (the 'know-how'). The middle layers serve to connect the top and bottom layers (the 'know-what'). In other words, the middle layers show the means of delivering the technological resources to satisfy the commercial purpose (Phaal & Muller, 2007).

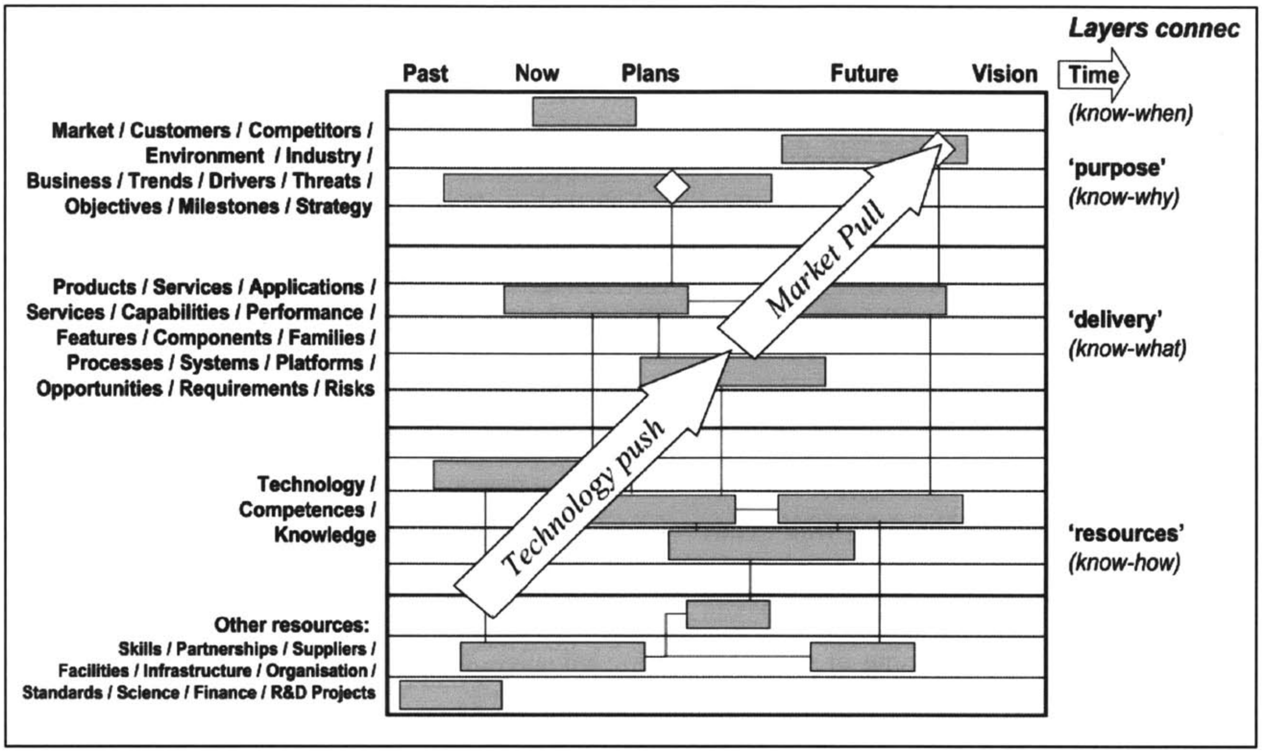

Figure 3: Generalized Technology Roadmap Architecture (Phaal, Farrukh, & Probert, 2004)

It is important to select a roadmap architecture that clearly communicates the strategic vision and illustrates how the technological and commercial perspectives link and align together. If the above template is used, it is crucial to gain consensus on the timeframe, the number of layers and the information contained in each layer early in the roadmapping initiative. Discussing the roadmap architecture will help align the stakeholders and clarify the intent of the roadmapping initiative.

2.2.2 The Process

The roadmapping process is an iterative and exploratory process by which the roadmaps are created. It must be a cross-functional and collaborative effort that will require the input of many participants across the organization. It provides the communication channels and organizational linkages that allow the stakeholders to share information and perspectives in order to develop an aligned and integrated strategy. The roadmapping process is critically important because its execution is the mechanism that facilitates the learning, knowledge-sharing and cross-functional collaboration that drives positive behavioral changes within an organization. For these reasons, the process of roadmapping is often considered more beneficial than the actual roadmaps.

Roadmapping can be classified into three phases – initiation, development and integration. Gerdsri & Vatananan (2007), Garcia & Bray (1997), and Phaal, Farrukh & Probert (2007) discuss the key objectives and tasks for each phase.

Phase I: Initiation

The initiation phase lays the groundwork for the subsequent development phase and is a critical step to the overall success of the initiative. During this phase, the roadmapping team is formed and the vision for roadmapping is developed and communicated to the key stakeholders.

The needs, objectives and scope of the roadmapping initiative are agreed upon and articulated. The roadmapping process and the roadmap architecture are developed. The necessary resources are determined and the key participants are identified. The overall purpose of the initiation phase is to build a strong cross-functional team to develop the vision for roadmapping and build support for the initiative among the key stakeholders.

Phase II: Development

The goal of the development phase is to execute the roadmapping process and create the roadmaps. Developing the roadmaps requires sharing knowledge among many participants with very different perspectives. Although the workshop-based approach is the most common method of conducting this phase, a few different approaches to the roadmap development phase are discussed below.

Phaal, Farrukh, and Probert (2007) have developed the T-Plan process, a workshop-based approach to technology roadmapping. The standard process consists of four workshops that brings "together key stakeholders and experts to capture, share and structure knowledge about the issue being addressed, to identify strategic issues, and to plan the way forward." Each of the first three workshops focuses on one of the layers of the roadmap, for example the market, the products or the technology. The fourth workshop focuses on integrating the knowledge from the first three on a timeline to create the roadmaps.

Gindy, Arman and Cavin (2009) have developed the strategic technology alignment roadmap (STAR) methodology, which uses a workshop approach and a software package to integrate and align the business, market, product, technology and R&D strategies. The major activities include requirements capture, technology benchmarking, technology watch, strategic fit, project assessment and portfolio selection. Gindy, Cerit and Hodgson (2006) propose a roadmapping process for manufacturing enterprises, similar to the STAR method. The requirements capture activity consists of working through the data collection hierarchy to identify and prioritize the business drivers, the required capabilities, the technologies and the requirements. The results from requirements capture activity, along with the results from the technology watch and benchmarking, are then used to generate and evaluate projects in order to select the technology portfolio.

Garcia and Bray (1997) propose a seven step process to develop technology roadmaps, consisting of 1) identifying the focus of the roadmap, 2) identifying the critical system requirements, 3) specifying the major technology areas, 4) specifying the technology drivers and their targets, 5) identifying technology alternatives and their timelines, 6) recommending technology alternatives and 7) creating the technology roadmap report. A team of subject matter experts and a roadmapping facilitator should execute the process.

The product of the development phase is a first draft of the roadmap document. The desired outcome from developing the roadmap is cross-functional communication, knowledge sharing and strategic alignment.

Phase III: Integration

During the integration phase, the successes and failures of the initiation and development phases are reviewed and the roadmaps are critiqued. The goal of the integration phase is to integrate roadmapping with other business processes to create a sustainable roadmapping process that will continuously evolve and improve.

2.2.3 Success Factors and Barriers to Success

Roadmapping is a challenging endeavor that requires broad support and collaboration across several functional and business units. It is a complex process, requiring the synthesis of many different perspectives and large amounts of information. Due to the complexity of the process, it takes time for the benefits of roadmapping to be realized, as the company learns, implements, and evolves the process into a useful practice. Roadmapping is also a flexible technique and it is important that it be tailored to fit the company's objectives, structure and culture. These factors present significant challenges for any company attempting to implement roadmapping. The three main challenges facing companies that choose to use roadmapping are 1) keeping roadmapping 'alive', 2) initiating roadmapping and 3) developing a robust roadmapping process (Phaal R. , Technology Roadmapping, 2003).

Barriers to Success

Lack of data/information/knowledge is the most cited barrier to success for roadmapping initiatives (Phaal R. , Technology Roadmapping, 2003). Roadmapping is an effective tool for capturing, sharing, linking and aligning knowledge of the different stakeholders but it is not a substitute for other technology management tools. The creation of the knowledge is a separate activity that precedes roadmapping. In the integrated technology management framework proposed by Foden and Berends (2010), this activity falls under the Identification and Monitoring stage and has its own tools and processes that output the information required for roadmapping.

The second barrier to success most often cited by companies attempting roadmapping is the **distraction from short-term tasks and work overload** resulting from the roadmapping initiative (Phaal R. , Technology Roadmapping, 2003). Most often, the need to complete immediate tasks takes precedent over longer-term improvement initiatives. Repenning & Sterman (2002) and Morrison & Repenning (2011), through system dynamics analysis of process improvement initiatives, find that the failure of process improvement initiatives is often the result of this trade-off for time-constrained employees. In an effort to complete short-term tasks, people will forego, or use shortcuts for improvement work, despite the longer-term detrimental impact of such actions.

Success Factors

The three most-cited factors leading to successful roadmapping are **1) a clear business need, 2) a strong commitment from senior management and 3) the involvement of the right people and functions** (Phaal R. , Technology Roadmapping, 2003).

Due to complexity of roadmapping, the level of resources required and the time-delay of realizing the benefits, successfully initiating and maintaining a roadmapping initiative is a significant challenge. Establishing a clear business need and strong leadership support motivates the participants to invest the required effort and creates confidence among the participants that the initiative will persist. Strong and visible leadership support and commitment must be communicated across the organization to gain the broad participation required.

Involving the right people is another critical success factor. In addition to a strong understanding of the subject matter of interest, roadmapping requires leadership, teamwork, persistence and the ability to understand other stakeholders' perspectives. Gerdsri and Vatananan (2007) discuss the involvement of the participants during the different phases of roadmapping and highlight key attributes of the various participants. Although the specifics will not be discussed here, it is extremely important that the participants be carefully chosen before embarking on the roadmapping journey.

2.3 Manufacturing Technology Roadmapping

The use of technology roadmapping as a tool for developing and deploying an integrated technology strategy within corporations around the world is becoming more common, as organizations realize its potential benefits. The author wishes to extend the application of technology roadmapping to manufacturing technologies, particularly in advanced technology companies such as Raytheon SAS. The main difference between the engineering and manufacturing technology roadmaps, is that the manufacturing technology has an additional dependency in the value chain to the customer. In other words, the manufacturing technologies add value indirectly ("indirectly-valued technology"), by enabling production of engineering technologies that directly deliver ("directly-valued technology") to the customers. Therefore, while the engineering technologies directly accomplish the business objectives, the manufacturing technologies only indirectly accomplish the business objectives.

Another important implication of the additional dependency is the different frame of reference between the "directly-valued" and "indirectly-valued" technologies. In other words, advances in "directly-valued" technologies will typically advance in line with company's existing capabilities to achieve its business objectives, whether incremental or breakthrough, while these advances may require completely different "indirectly-valued" technologies for production. For example, a company may upgrade a technological capability by changing the material of a "directly-valued" technology to improve performance. While this may be an incremental improvement for the "directly-valued" technology, it may necessitate a complete change of the "indirectly-valued" technologies to ones with which the company has no experience. On the other hand, if a manufacturing company competes directly on its manufacturing capabilities, then the manufacturing technologies are the "directly-valued" technological capabilities. This is an important distinction and is a result of the different reference frames between those technologies on which the companies directly compete and those technologies that support.

The difference between "directly-valued" and "indirectly-valued" technologies will influence the roadmapping process and the roadmap architecture. The remainder of this paper will focus on roadmapping the manufacturing technologies, "indirectly-valued" technologies in an advanced product technology company such as Raytheon SAS.

2.4 Summary

Technology management is an important capability for companies that use technology as a competitive advantage. It can be decomposed into six stages that follow the life cycle of technologies, from identification through exploitation of the technologies. Each stage has a purpose and a set of appropriate tools, that when integrated forms a complete technology management solution.

Technology roadmapping is an effective tool for the Selection and Approval stage of technology management, whereby the opportunities for technological solutions are evaluated within the strategic context of the company. Roadmapping enables the stakeholders to develop and communicate a shared representation of the strategic vision for the technological opportunities, to prioritize these opportunities within the business objectives, and to optimally allocated resources toward the development and acquisition of new technological capabilities.

Although technology roadmapping is a simple concept, its implementation and sustainment proves to be challenging. It requires broad collaboration and support across the organization. Although guidelines and processes for roadmapping exist within industry and academia, it must be tailored to the strategic context in which it will be implemented. The companies that succeed in implementing an effective roadmapping process develop the important core competency of strategic technology planning that enables them to gain the most value from the investments in technological capabilities.

For the remainder of this paper, we will focus on the initiation of roadmapping and the development of manufacturing technology roadmaps within Raytheon Space and Airborne Systems.

3 Raytheon Space and Airborne Systems

This chapter was almost entirely written by Louis Grillion (Creation and Sustainment of Manufacturing Technology Roadmaps, 2012) and provides background information on the defense industry, Raytheon Corporation, Raytheon Space and Airborne Systems (SAS), and the department where the project began, Advanced Manufacturing Engineering (AME). The intention is to provide a broad overview of the environment in which the project took place so that the reason why decisions were made can be better understood.

3.1 Defense Industry Background

The defense industry as it is called in the United States is the group of companies that supply products and technologies to the United States Government. "The mission of the Department of Defense is to provide the military forces needed to deter war and to protect the security of our country" (About the Department of Defense). DoD is in charge of the United States Government defense budget spending, including all money to support national security and the different military branches; Army, Air Force, Navy, Marine Corps, and Coast Guard. The DoD's proposed defense budget is $671 billion for fiscal 2012 (DOD Releases Fiscal 2012 Budget Proposal, 2011).

The DoD is Raytheon SAS's largest customer. Being a supplier to such a large government organization comes with unique challenges. Since the DoD is so large and diverse there are a variety of systems that it has put in place to help manage the procurement of products and services from contractors such as Raytheon. These systems are talked about in further detail in Appendix A. The take away is that there are a variety of systems that are complex and focused on technology development. They require technology maturity to reach a certain milestones for contracts to be won. There is not a major focus on the manufacturing maturity of technology being developed by the DoD as visible by many of the acquisition milestones focusing on technology requirements instead of manufacturing requirements.

3.2 How the DoD Acquisition System Influences Companies

Companies in the defense industry typically focus on the technical milestones required to win the next phase of a contract. This is required because the technical requirements are a go, no-go issue. If a program does not meet the technical requirements that are set for it then it will not pass the milestone and will not be awarded a further contract.

Contracts used to be awarded on which company could provide the most advanced technology with little weight given to the actual manufacturing costs. This created the environment where companies were focused on developing a very technically capable technology that would meet or exceed the performance requirements.

"In Defense, practice is often to demonstrate the performance of complex systems, then change the design late in development for production / support" (Gordon, The Need for Manufacturing Innovation and Readiness, 2008). This practice results in costly changes to the system; creating cost and schedule overruns. This is an artifact of the Cold War era when any technical advantage over other countries was worth the required investment.

"GAO's reviews of weapons over three decades have found consistent cost increases, schedule delays, and performance shortfalls. The nation's growing long-range fiscal challenges may ultimately spur Congress to pressure DoD to cut spending on new weapons and to redirect funding to other priorities" (United States Government Accountability Office, 2007).

Based on 62 programs	Technology Status at Beginning of Development	
	Mature	Immature
RDT&E Cost Increase	2.6%	32.3%
Acquisition Unit Cost Increase	<1%	>30%
Average Schedule Delay	1 month	20 months

Figure 4: Cost and Schedule Overages of Acquisition Programs (Gordon, 2008)

As the world changes the needs of our government are changing too. This means that DoD is much more cost conscience in the current environment of increasing national debt and ballooning costs. One way to try and control costs is to move away from cost plus contract to fixed price contracts. There are a variety of different cost plus contracts that exist such as cost plus fixed fee and cost plus incentive fee. Cost plus contracts can create an environment where there is less of an incentive to reduce the manufacturing cost of a product. This is why the DoD is moving away from cost plus contracts to fixed price contracts (RMS, 2011).

Numerous studies have been conducted to try and determine the cause of schedule and cost overruns (United States Government Accountability Office, 2007). Figure 4 clearly illustrates that having an immature technology greatly increases the risk of cost and schedule overruns. Technology is considered immature prior to reaching Milestone B (equivalent to TRL/MRL 6) and is considered mature post Milestone B. TRLs and MRLs are discussed further in the following section. The immature technology can be at any point along the research, development, test, and evaluation (RDT&E) phase. The DoD is trying to encourage contractors to mature technologies, both design and manufacturing, further along before they are used in programs.

3.2.1 Manufacturing Readiness Levels

The DoD has also begun to try and encourage manufacturing preparedness in hopes of preventing cost and schedule overruns due to manufacturing. They are trying to accomplish this through manufacturing readiness levels (MRLs). MRLs are a measure of a technology's maturity (and attendant risk) from a manufacturing perspective taking into account design, manufacturing technology and processes (OSD Manufacturing Technology Program, 2011). The DoD has a similar rating scale for design technology called Technology Readiness Levels (TRLs). For a complete list of the various Manufacturing Readiness Levels and their definitions please see Appendix B - DoD Manufacturing Readiness Level Definitions.

3.2.1.1 Manufacturing Readiness Assessments

Manufacturing Readiness Assessments (MRAs) are a structured evaluation of a technology, component, manufacturing process, weapon system or subsystem. Performed to:

- Define current level of manufacturing maturity (MRL)
- Identify maturity shortfalls and associated costs and risks
- Provide the basis for manufacturing maturation and risk management

MRAs are becoming mandatory on some programs that the DoD funds. This means that the contractors are required to demonstrate that their manufacturing technology is developed to the appropriate point before passing the various milestones. This is verified by DoD personnel that conduct the MRA in similar fashion to an audit.

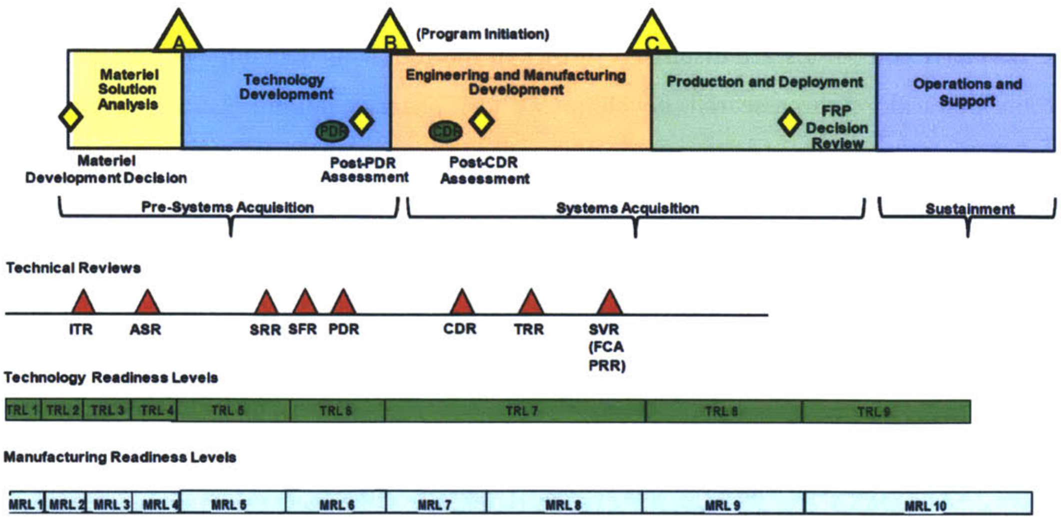

Figure 5: Technology Development and Maturation Life Cycle

Figure 5 shows how the manufacturing and technology readiness levels line up with the Defense Acquisition System (DAS) phases and milestones.

"MRLs and MRAs were developed to help succinctly identify manufacturing requirements and risks in a building block approach that can start in S&T (Science & Technology), build throughout the subsequent acquisition phases and culminate in a program that is ready for production, on cost and schedule, and meets performance requirements" (Joint Defense Manufacturing Technology Panel (JDMTP), 2009).

Here it is clearly demonstrated that DoD is trying to help programs achieve cost and schedule targets by helping them to recognize and measure the maturity of their technologies and manufacturing capabilities.

3.3 Raytheon Background

Raytheon Corporation (NYSE:RTN) is a technology and innovation leader specializing in defense, homeland security and other government markets throughout the world (Raytheon, 2011). Raytheon employs 72,000 people worldwide and had 2010 sales of $25 billion. The headquarters are located in Waltham, MA. Raytheon is made up of six business units – Space and Airborne Systems (SAS), Integrated Defense Systems (IDS), Intelligence and Information Systems (IIS), Missile Systems (RMS), Network Centric Systems (NCS) and Raytheon Technical Services Company LLC (RTSC). The project discussed in this paper was completed at Raytheon Space and Airborne Systems.

3.3.1 Raytheon Space and Airborne Systems

The focus of Raytheon SAS is on a variety of sensors systems including various radar, targeting, and space systems that operate across the electromagnetic spectrum. SAS has 12,500 employees with 2010 revenue of $4.8 billion. Its headquarters are in El Segundo, CA (Raytheon, 2011).

SAS is broken up into three main mission areas Tactical Airborne Systems (TAS), Intelligence, Surveillance, and Reconnaissance Systems (ISRS), and Space Systems (SS). In the first quarter of 2011 Raytheon SAS acquired Applied Signals Technology (AST), now called Raytheon Applied Signal Technology (Applied Signal Technology, Inc. , 2011). Each of these mission areas are in charge of programs that meet customer needs in their area of focus. An example would be that TAS is responsible for the F-18 radar program. Please refer to Appendix C SAS Mission Areas for more information on the specific mission areas.

SAS was created by the acquisition of various aerospace defense companies in the 1990's, including Hughes Aircraft Company (1997) and the defense business of Texas Instruments (1997). These two companies competed with each other in a variety of different markets and had very distinct organizations from each other and from what was Raytheon at that time.

Since SAS was formed by a variety of different companies, the culture of each took a while to slowly get absorbed into the Raytheon culture and each facility to this day still retains some of its original history. Part of the culture of Hughes Aircraft was basic research and development. This focus on research and development led to many new advanced technologies, which were successfully commercialized. It was innovation that drove the success of the company.

3.3.1.1 SAS Organizational Structure

The organizational structure of SAS is very important to understanding the context of the project. SAS operates in a complex matrix structure. There are functional departments such as engineering and operations. These departments supply the resources necessary for programs to be completed. There are then various programs, which are focused on delivering a product to the customer.

The functional department managers are responsible for their specific function. Take the example of engineering, there is a VP of engineering. As you go down the engineering hierarchy, there are more specific engineering centers that focus on an engineering specialty. Lower still are the functional departments, which are responsible for the training and development of their employees. They need to make sure that there are enough trained employees in the right areas to support the business.

There is a program for each contract SAS has with a customer. The programs are responsible to fulfill the contract and deliver the product to the customer. To achieve this they need functionally trained employees. They pull these employees from the functional departments.

Below is a chart that visually depicts this. It shows various functional departments on the left hand side. Across the top are the mission areas and specific programs within each mission area. These programs then pull in the necessary functional employees to complete the work. This is depicted with an X. Functional departments include; engineering, operations, supply chain management, contracts, finance, etc.

	Tatical Airborne Systems (TAS)		Space Systems (SS)		Intelligence, Surveillance & Reconnaissance (ISR)		
	Program 1	Program 2	Program 3	Program 4	Program 5	Program 6	Program 7
Engineering	X	X	X	X	X	X	X
Operations		X	X	X	X		X
Supplay Chain Management		X		X	X		X
Mission Assurance (Quality)		X		X	X	X	X
Functional Area 5				X	X	X	
Functional Area 6				X			

Figure 6: SAS Matrix Organization

It is important to recognize that each functional department, mission area, and program has its own amount of influence. Different programs may have different amounts of influence based on the size (dollar amount), strategic importance and visibility of the program. The same is true for functions; larger functional areas tend to have an easier time driving change when compared to smaller "supporting" functional areas.

There is one more additional layer of complexity to this matrix. Engineering design work does not take place in the same location as manufacturing for some of the products. This is due to the large size of Raytheon SAS with major locations in California, Texas, and Missouri. This gives rise to an additional reporting structure where there are also site hierarchies and responsibilities.

Advanced Manufacturing Engineering

Advanced Manufacturing Engineering (AME) was created in 2005. AME was created as a bridge between the design engineers and the factories where manufacturing takes place. The focus of this group was to take manufacturing knowledge and help design engineering incorporate it into their design to create producible products. The vision of AME was as follows, "Advanced Manufacturing Engineering delivers technical & process solutions that enable manufacturing operations to yield high quality, on-time and cost effective products." AME reported up through the VP of Operations.

This role was initially developed for AME, but the department struggled partly due to the matrix structure that exists at SAS. Some programs did not want to fund AME to help the design engineers develop manufacturable products. In a few cases the design engineers did not want to be told how to do their design work. They were not always worried if the product could be manufactured easily, they were focused on the performance characteristics. It was the responsibility of operations to figure out how to manufacture the designed product for the desired cost.

After many years of existence it was decided that AME would be dissolved in 2011. The industrial engineering group, which was tasked with factory improvements, would stay in operations. The rest of AME which supported the development of producible products would be moved over into engineering. The hope was to align the groups in a more efficient manner so that new technologies being developed would be designed to be manufactured easily.

It is important to note that the incentives for engineering can be tuned to more closely align to the current state of the business. Engineering is still incentivized on developing new high performing technologies. This is an artifact of the old defense days when technology performance was priority number one. As the various DoD sources state (referenced previously section 3.1 – Defense Industry Background), this is no longer the case. DoD who is the primary customer for Raytheon SAS and Raytheon as a whole, wants a product that meets performance requirements, but that also meets cost and schedule requirements. This means that manufacturing considerations need to be taken into account during the initial design.

3.3.2 Manufacturing at SAS

Raytheon SAS is in the aerospace/defense industry. As such, many of the products that are developed and manufactured are low volume. This is especially true of the space programs where only one or two instruments or satellites may be manufactured. As a corollary to this, since limited quantities of products are produced, the customer wants the product customized to their specific mission needs. This means that there is a wide variety of different variations of a product.

As a technology innovator SAS does not want to manufacture every piece of every system they make. This means that they must rely on their suppliers to provide components and sub systems to them. SAS then integrates these into final system level assemblies that are then tested. When a new technology is developed in house that provides a competitive advantage SAS will develop the manufacturing processes in house to retain the competitive advantage. This is where manufacturing technology roadmaps can have a real impact on how business is done. They support the development of manufacturing capabilities that are key differentiators, while at the same time make sure that suppliers are capable to support non-strategic manufacturing requirements.

Manufacturing technology roadmaps give Raytheon SAS the ability to see what their existing manufacturing capabilities are, what new manufacturing capabilities they need in the future, and what gaps exists between these. With this information operations leadership can make informed decisions so that new manufacturing capabilities are ready in time to support the customer. They can also determine whether a new manufacturing capability should stay in-house, or if it can be outsourced. This is a key strategic decision that roadmaps seeks to enable. Manufacturing technology roadmaps also allow operations leadership to determine which factory should develop the new manufacturing technology if it is to be developed in-house based on current and future capabilities.

4 Setting the Stage for Roadmapping

Roadmapping is a complex and challenging process that requires broad and cross-functional participation. Because the initiative is dependent on this participation, it is important to invest the time to engage the stakeholders early on to understand their perspectives and concerns. The various stakeholders perceive different needs and objectives for the roadmapping initiative. The insight gained through these interactions is critical to entire initiative, enabling the roadmapping team to incorporate the stakeholders' objectives and concerns into the roadmapping initiative and to align the stakeholders.

With a broad understanding of the issues facing the company, the roadmapping team is ready to set the scope and objectives of the roadmapping initiative. The scope and objectives are down-selected from a complete list of issues perceived by the stakeholders, based on their ability to be addressed by roadmapping and their relative importance. If a key stakeholder perception's of a need is not addressed by the down-selected list, the issue may be added to the final scope and objectives in an effort to gain their support and participation. It is important that the key stakeholders have a valid reason for participating in the initiative.

In this chapter, we will discuss the process of identifying and understanding the stakeholders, investigating the needs for roadmapping and defining the scope and objectives for the roadmapping initiative at Raytheon SAS. The goal of the activities described in this chapter is to develop an understanding of the strategic context and the culture of Raytheon SAS.

4.1 Stakeholder Analysis

As with any broad process improvement initiative, understanding who the stakeholders are and how they impact the initiative is important. A stakeholder analysis was performed to identify all of the stakeholders that will be involved or affected by the roadmapping initiative. The goal is to better understand the following:

- What are their interests?
- What is the relationship between each of these stakeholders?
- What does each stand to gain or lose from the project?
- What role should each stakeholder play in the implementation of your project?

- How willing and/or able are they to support your project?

It is recommended that a stakeholder analysis be performed as soon as possible and in as much detail as possible, even though the analysis will undoubtedly be in error this early in the initiative. This analysis is an effective method to help the roadmapping team identify the stakeholders and to better understand their perspectives on the initiative. It will also help the team understand the network of relationships among the stakeholders and help determine how to navigate and engage the organization. Figure 7 provides an illustrative example of a tool for a stakeholder analysis.

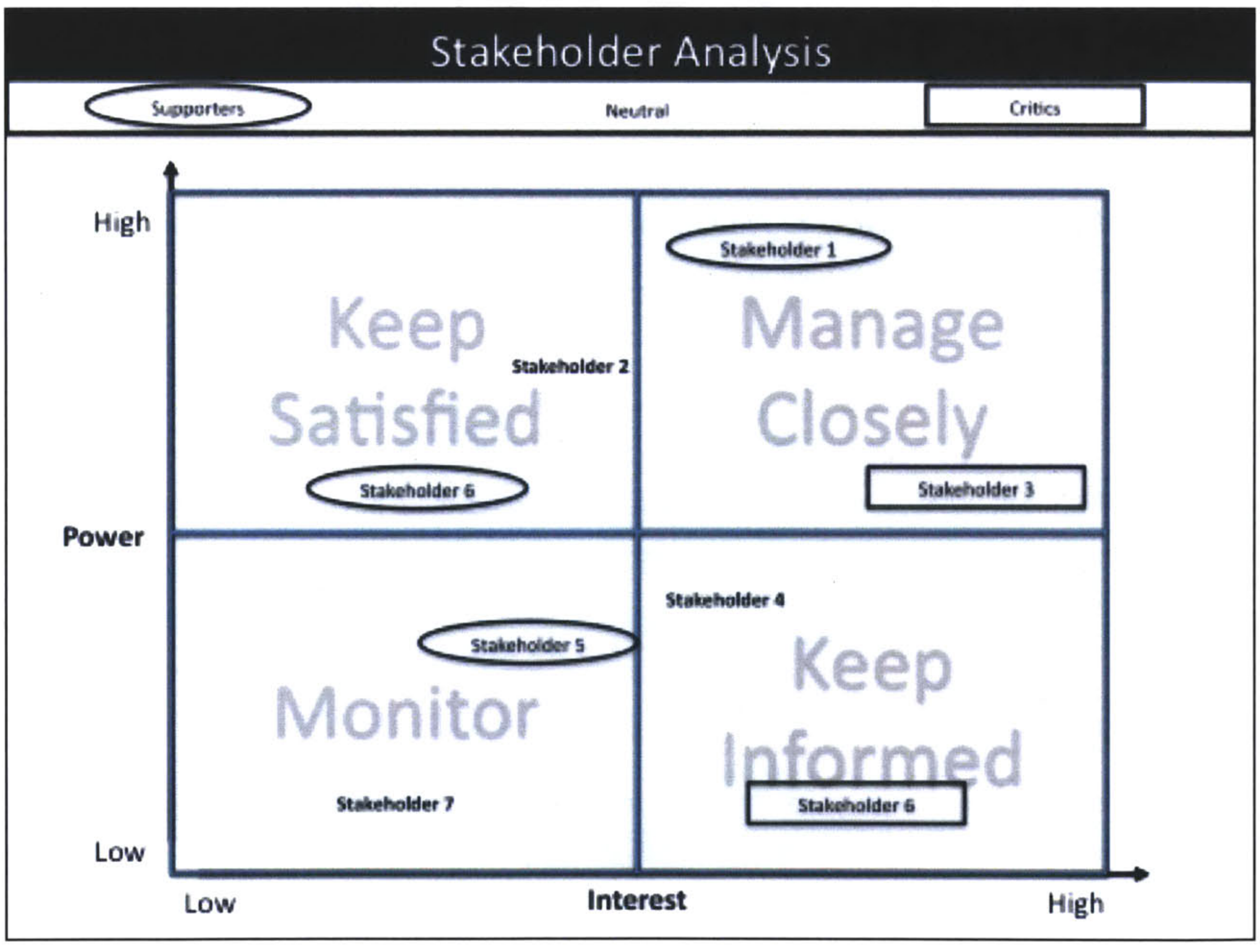

Figure 7: Power/Interest Grid for Stakeholder Prioritization (Thompson, 2012)

The stakeholder analysis identifies the stakeholders and provides insight into the impact they may have on the initiative. Understanding the concerns and perspectives of each of the stakeholders is crucial to the success of the roadmapping initiative. The next step is to engage the stakeholders to identify the issues driving the need for roadmapping.

4.2 The Need for Roadmapping

Establishing the needs for roadmapping will provide the foundation for all of the future roadmapping work, as the roadmaps and the roadmapping processes will be based on the roadmapping team's understanding of the stakeholders' perceived issues. This is an essential step in creating alignment between the stakeholders and in gaining their support.

To better understand the needs for roadmapping and the stakeholders' perspectives, the roadmapping team conducted several interviews, discussions and meetings with as many of the stakeholders as possible. A typical engagement consisted of the roadmapping team providing a brief overview of roadmapping, its general purpose and the need for roadmapping as perceived by the roadmapping team. The roadmapping team then requested the stakeholders to provide feedback and input on the issues with which they struggle. The stakeholders provided a broad range of issues and the roadmapping team did not initially attempt to confine the discussion to those issues addressable by roadmapping. Conducting the interactions in this manner provided insight into the need for roadmapping, the perspectives and responsibilities of the stakeholders, and the flow of information through the company.

One stakeholder's perception of the need for roadmapping was often found to be very different from that of another stakeholder's. The perceived need for roadmapping varied by stakeholder's organizational level (i.e., VP, Director, Factory Manager, Engineer) and group (i.e., functional unit, business unit, factory, program), as well as their job responsibilities. From the complete list of perceived needs, the roadmapping team organized and prioritized the issues based on its ability to be addressed by roadmapping and its importance on the company's competitive advantage. The most common and relevant needs for roadmapping can be organized under the three broad needs listed below.

- Link manufacturing technologies to products and markets
- Facilitate communication across the organization
- Align the manufacturing technology strategy with the product and business strategies

Without a process to address these three needs, the company struggles with allocating its resources for the development and acquisition of new manufacturing technologies. The requirements for the new manufacturing technologies, are not aligned with their business drivers nor are they well understood. **The**

lack of an effective strategic planning process for the manufacturing technology has two major effects: 1) production exceeds budgets and schedules, and 2) the strategic impact of sourcing decisions are not well understood.

Roadmapping is needed to develop and align the company's manufacturing technology strategy with the product and business strategies, and to communicate the strategic vision to the company. Roadmapping provides a method to clarify a complex environment in order to guide the allocation of resources for the development and acquisition of manufacturing technologies, to select and advance its core capabilities and to deliver products on time and under budget.

4.2.1 Linking Manufacturing Technology to Products and Markets

Linking the manufacturing technologies to the products and the markets is a key need for roadmapping. This linkage serves the purpose of identifying the manufacturing technologies required for the production of new products and the timeline for their development and acquisition. The linkage will help ensure that the investments in the new manufacturing technologies occur early enough for them to be "production-ready" at the scheduled start of production.

The absence of "production-ready" manufacturing technologies for new products was found to be a major contributing factor to the production schedule and budget overruns being experienced. Factories and manufacturing engineers not obtaining information about the production timelines and volumes are two aspects of this unpreparedness. Immature manufacturing technologies are another aspect and is especially important due to the long lead times required to develop new manufacturing technologies. Some of the reasons for immature manufacturing technologies include:

- Factories are not aware of new products in the pipeline
- Funding is not available to mature manufacturing technologies
- Manufacturing is not engaged during the early product development phases of a program
- Internal manufacturing capabilities do not significantly factor into new product development

In general, manufacturing technologies are not being developed concurrently with the new product technologies. The need for the development and/or improvement of the manufacturing technologies is driven by two factors; 1) the development of new product technologies often require innovative manufacturing technologies and 2) the natural evolution of products require tighter tolerances and better control. Both factors drive the need for new and more advanced manufacturing technologies.

Information not reaching the right people

Factories are often not aware of new products being developed and are therefore unable to develop or acquire the necessary manufacturing technologies. In most cases, the factories deal with immature manufacturing technology either by reactively investing time and money in the required manufacturing technology or by starting production with immature manufacturing technology. The results are delayed product deliveries and budget overruns, either from upfront investment of time and money to develop the required technologies or the low yields and excessive rework when using immature technologies. In other cases, factories deal with this issue by anticipating the future production needs and proactively investing in the manufacturing technologies. Although this prepares the factories for production in the cases that they correctly anticipate their needs, this practice unnecessarily exposes the factory to the risk of making unnecessary investments. Whether the factories choose to react or anticipate, the result is less than optimal and can be improved. Therefore, a process to link the development of new manufacturing technologies with the development of new product technologies is critical for the effective allocation of resources. A process to effectively identify gaps in manufacturing technologies and close these gaps prior to the start of production is a key challenge facing Raytheon SAS today.

Funding for the development of manufacturing technologies is not available

In other cases, manufacturing technologies are often not matured past the ability to make a small number of units in a laboratory environment. Due to the uncertainty of winning contracts to for the production phase, new product technologies are often prototyped without consideration for the actual production technologies necessary to produce them in a production environment. Therefore, the manufacturing technologies are not matured beyond the ability to produce the system in a lab environment, corresponding to MRL 4. The result is that the product technologies are being matured to win contracts for the next phase of development but the manufacturing technologies are not matured. The manufacturing technologies remain at MRL 4 until the contract for production is awarded, at which time the design is relatively fixed without the proven production capabilities. Despite the manufacturing engineers being aware of the need to mature the manufacturing technology, the funds are not available until it is too late.

In addition to the development of new manufacturing technologies is the improvement of existing technologies. While it may not make economic sense to improve a particular manufacturing technology for any one product, it may make sense to improve it if it will be used for multiple products. There are opportunities to improve existing manufacturing technologies to raise yields, reduce scrap and rework, and reduce costs. For this to be possible however, manufacturing must be informed of the strategic direction of new product development so that they can align the development of manufacturing technology accordingly and make the business case required to receive funding.

Evaluating business opportunities on the total cost of product delivery

Investments in new technologies, both product and manufacturing, is a critical strategic decision that will define the future of the company. When evaluating a new business opportunity, the total cost of winning that business must be well understood and evaluated. With production constituting a large portion of the total cost and time to deliver products, it is imperative that this be considered in the decision process. Because production is toward the end of the development lifecycle however, it is often not given the proper consideration. It was found that the investment in new product technologies and those in new manufacturing technologies are not evaluated together, but as separate decisions.

The ability to evaluate business opportunities on the total cost of winning the business is important for the success of the company for two reasons. First, the company needs to have a good understanding of the total cost of new products to be able to prioritize the investments in new technology. Second, the customers need assurance that the company can deliver products according to the budget and schedule set forth. As the trend toward fixed-price contracts continues, the importance of evaluating the total cost of meeting customer demands continues to grow.

Summary of Needs

Linking the manufacturing technology to the products and markets clarifies the investment opportunities by showing how the investments deliver value to the customers and the company. A particular manufacturing technology may be required for the production of several products and these linkages will show these dependencies. It also highlights the gaps in the manufacturing technology required for the future production of products and helps evaluate business opportunities on the total cost of delivering the products. Linking the manufacturing technology to the products and business opportunities aligns their development and acquisition to the products being development, ensuring the investments are optimized across Raytheon SAS and the manufacturing technologies are "production-ready" when needed.

Ultimately, understanding these linkages will help ensure product deliveries meet the schedule and budget, making Raytheon SAS more competitive and profitable.

4.2.2 Facilitating Communication Across the Organization

Roadmapping facilitates communication across functions, factories, programs and organizational levels, which is critical for achieving and maintaining alignment across the company. Communication between business development, engineering, manufacturing and supply chain helps ensure new product development considers the entire product life cycle and business objectives. Communication across the factories and programs helps ensure technologies and capabilities are leveraged across the company. Communication across the organizational levels helps senior management understand situation on the ground and helps the lower levels understand the strategic direction. Roadmapping is an effective tool for facilitating communication and can help drive the formation of these communication channels.

Communication between the various functions is important for understanding the trade-offs inherent in new product development. Understanding these trade-offs and making decisions that consider the design, production and business objectives requires cross-functional communication and alignment, at all levels of the organization. In our discussions with the stakeholders, it was apparent that those stakeholders that have the right communication channels, whether formal or informal, have a much broader perspective of how their responsibilities fit into the bigger picture and are able to make better decisions for the company.

Coordinating the manufacturing technologies across the organization (factories, programs, products) is important for preventing unnecessary or unwanted redundancies in the manufacturing technologies. Currently, individual factories and programs allocate investments in new manufacturing technologies with little horizontal communication. Therefore, investments may be allocated for the development or acquisition of a particular manufacturing technology by more than one factory or program. The result is locally optimized investment allocations and redundant manufacturing technologies.

Effective communication is a critical and fundamental factor in any company's ability to operate effectively and compete in industry. Communication is also a challenge facing many companies and roadmapping is a tool that has helped address this issue in many companies.

4.2.3 Aligning the Manufacturing Technology with the Business and Product Strategies

Aligning the manufacturing technology with the business and product strategies is an overarching need that has significant implications. An integrated strategy provides vision and alignment for the entire company, guiding the decisions, actions and investments to achieve a set of business objectives. It aligns the business development, engineering, manufacturing and supply chain functions in order to allocate resources to enter markets, develop products, develop core capabilities and meet customer demand with a common objective.

The strategy drives the allocation of resources and without an integrated strategy, resources are not optimally allocated and do not effectively work toward the same goal. Resources may be allocated toward developing a new product but if that product cannot be produced economically due to lack of resources invested in the required manufacturing technologies, value is not delivered to the customer or the company. In this case, the resources were wasted. The ability to create an integrated strategy and appropriately allocate resources that achieves the business objectives is crucial for maintaining competiveness.

The most important competency of a company is its ability to determine what capabilities to invest in and which to outsource (Fine, 1998). The sourcing decision is a critical and challenging process. The new product development team is responsible for making the make-buy decision and often chooses to outsource the part for a couple of reasons. The first reason is based on cost. Because suppliers are incentivized to bid low for new business, development teams are able to obtain quotes for parts below the cost that the part can be made internally. In reality, the actual cost of the parts from suppliers often exceeds the supplier-quoted cost, as well as the cost to produce internally. The second reason is that suppliers are eager to confirm that they are capable of making complex parts to win business when in fact they are often not capable without additional investment and learning. The result is two-fold; opportunities to develop strategic manufacturing capabilities internally are missed and outsourced parts exceed budgets and delay schedules.

Roadmapping provides a process for developing and communicating an integrated technology strategy that can guide the effective allocation of resources to develop its core capabilities and deliver value to its customers and shareholders. The manufacturing technology strategy is one component of this integrated strategy and aligning it with the business, product and R&D strategies provides the vision into the future of the company's manufacturing technology and its core capabilities.

4.3 Scope and Objectives

Roadmapping is a tool to develop, align and communicate the strategic vision for the company's manufacturing technology. The overarching goal of roadmapping is to:

> **Establish a strategic planning process to develop and communicate the manufacturing technology strategy in order to efficiently allocate resources for the development and acquisition of manufacturing technologies that advance the company's core capabilities and satisfy production requirements.**

The needs for roadmapping identified by the stakeholders and the overarching goal can be translated into a list of objectives for the roadmapping initiative. The objectives for Raytheon SAS's Manufacturing Roadmaps include:

- Align manufacturing technology strategy with the R&D, product and business strategies
- Link manufacturing technologies to their product and business drivers
- Identify critical manufacturing technologies, the gaps and the timelines for development
- Determine the time-phased investments to mature the technologies and close the gaps
- Facilitate the allocation of resources across the entire manufacturing technology portfolio
- Coordinate the development and acquisition of manufacturing technologies
- Create communication channels and information flows for the management of the technology
- Identify manufacturing technologies that are critical for the company's core capabilities
- Provide the strategic guidance for the make/buy/where decisions
- Benchmark against other Raytheon businesses, competitors and industry

The scope defines the boundaries for the roadmapping initiative. The roadmapping initiative will provide a 5-year strategic outlook and will focus on the key manufacturing technology (equipment, facilities and processes) required for the production of the company's products, both internal to the company and that of its key suppliers. All sources of funding will be considered, including Internal Research and Development (IRAD), Capital, Contract Research and Development (CRAD), and Manufacturing Technology Grants (ManTech).

Although the roadmapping team considered including the manufacturing technologies required for capacity expansion and/or cost reduction in the scope of roadmapping, we determined that it would not be included because of the relatively short lead times of acquiring and implementing already-proven manufacturing technology. Human resources are also not included. Both of these factors are important considerations and could be included in the scope of the future roadmaps.

4.4 Leadership Support

To conclude this chapter, we will discuss the importance of gaining the support and commitment of the leadership and stakeholders. At this point in the project, we have performed a stakeholder analysis and engaged the majority of the stakeholders to request their input on the needs for roadmapping and the issues relevant to them. This proved valuable in understanding the context for roadmapping and the stakeholders' perspectives. These engagements also served to foster goodwill and transparency between the roadmapping team and the stakeholders, providing the stakeholders with a voice in initiative. After defining the scope and objectives, the roadmapping team re-engaged the stakeholders to present our findings and recommendations for the roadmapping initiative. We presented the needs, scope, objectives and next steps for the roadmapping initiative. Although many of the stakeholders were not yet sold on the benefits of roadmapping, the support continued to grow and many began to offer more insight and resources for the roadmapping initiative. The importance of following up with the stakeholders became apparent later in the project, as it served to get the stakeholders thinking about roadmapping and communicating its potential benefits. Although the roadmapping initiative was thought (by some stakeholders) to be a fruitless effort with little chance of success, the perception was beginning to change and critical momentum was being built.

Support and commitment from leadership is crucial for roadmapping, especially during the initiation phase due to the exploratory nature of this phase. Leadership can effectively provide or prevent access to the people and information necessary for roadmapping. Roadmapping requires broad participation within the company and access to people and information has proved to be one of the major obstacles encountered thus far. It also requires a substantial upfront investment of company resources before the benefits are realized. After the initiation of a roadmapping process, the participants will need time to begin to expand their time horizons and develop the communication channels and knowledge to become successful contributors to the roadmapping effort. In a world where companies think about the next quarter or year, the delay between the initial effort and resulting benefit leads many companies to abandon the effort before the full benefit can be realized. With every roadmapping iteration, the task becomes easier and the benefits increase. Therefore, leadership must help overcome the initial obstacles and continue to provide support for roadmapping until the benefits can be realized.

Roadmapping has proved to be a valuable tool but implementing it has proved to be a substantial challenge. Therefore, it is imperative that leadership supports the effort and communicates this commitment to the rest of the organization.

4.5 Summary

Setting the stage for roadmapping consists of understanding the stakeholders, identifying the need, defining the scope and objectives and building support within the organization. Setting the stage takes time and resources, but the investment is necessary if a company is serious about implementing a roadmapping process. It is tempting to move through this part of the process quickly, but our findings show that doing so will only result in more challenges throughout the remainder of the initiative. Setting the stage for roadmapping is an important part of the process that deserves careful attention, as it provides the foundation for the entire initiative.

5 Design of the Roadmap Architecture

The roadmap architecture will provide the framework for the contents of each roadmap and their relation to each other. The roadmap structure refers to the layers of the roadmap and its timeframe. The layers contain the business drivers (know-why), the delivery mechanisms (know-what) and the resources (know-how) that will be linked together and aligned (Phaal & Muller, 2007). In addition to the roadmap structure (i.e., layers and timeframe), we will refer to the entire collection of roadmaps, including the Investment Roadmaps and the Technology Roadmaps, as the roadmap architecture.

In this chapter, the process of designing the roadmap architecture is discussed, which consists of identifying the information that will be contained in the roadmaps, establishing the roadmapping terminology, understanding the information collection hierarchy and finally, designing the architecture of the roadmaps. The goal is to design a roadmap architecture that effectively communicates the strategic vision and accomplishes the objectives set forth in Chapter Four.

5.1 Roadmap Content

The roadmap content refers to the information contained within the roadmaps, structured to develop and communicate the strategy for the manufacturing technology. Defining the roadmap content is the first step of designing the roadmap architecture, as the content will serve as the building blocks for the roadmap. Getting consensus on the roadmap content and terminology serves to align the stakeholders and focus the information gathering during the roadmap development phase.

The general roadmap content required for the Raytheon SAS Manufacturing Roadmaps is listed below.

- Current state of manufacturing technologies
- Manufacturing technologies required in the future
- The product and business drivers for the manufacturing technologies
- Development/maturation timelines for the manufacturing technologies and its drivers
- Time-phased investments for the development of the manufacturing technologies
- Knowledge of the manufacturing technologies available in the market

Although the roadmap content listed above generally describes the information to be contained in the roadmaps, it is too general to provide a clear understanding of the information. Attempting to gather the roadmap content at this point would prove difficult and much time and effort would be spent gathering large amounts of irrelevant information while often missing the relevant information. Before the architecture of the roadmaps can be designed, a common roadmapping language (terminology and definitions) should be created and the information collection hierarchy should be understood. Both tasks are discussed in the following sections.

5.2 Terminology and Definitions

Establishing common terminology and definitions for the roadmapping initiative is an important step in defining the roadmap content. It allows the participants to effectively and concisely communicate, ensuring that everyone understands each other. It will also facilitate the participants' understanding of the level of detail required for the purposes of roadmapping. The goal of establishing common terminology and definitions for the roadmapping initiative is to allow the participants to effectively communicate.

Understanding how time-consuming establishing definitions can be, the roadmapping team decided it was important to leverage language commonly used by the company whenever possible in an effort to not stall the effort. In some cases, definitions were developed or borrowed from other organizations when an adequate definition did not exist within the company vocabulary. The roadmapping team found that when roadmapping language was inadequate or not well understood by the majority of the participants, there were many inconsistencies and frustrations that surfaced later in the roadmapping initiative.

5.3 Information Collection Hierarchy

The information collection hierarchy refers to the organization and flow of information, beginning with the business drivers and ending with the investment decisions. The purpose of considering the information collection hierarchy is to understand the relationships and linkages between the business drivers and the investment decisions, which provides insight for designing the architecture of the roadmaps.

To determine the information collection hierarchy, the roadmapping team considered the flow of information within Raytheon SAS, focusing on how to arrive at the roadmap content previously established. The information collection hierarchy is specific to each company, although similar companies may have similar hierarchies. Figure 8 illustrates Raytheon SAS's information collection hierarchy relevant to technology roadmapping.

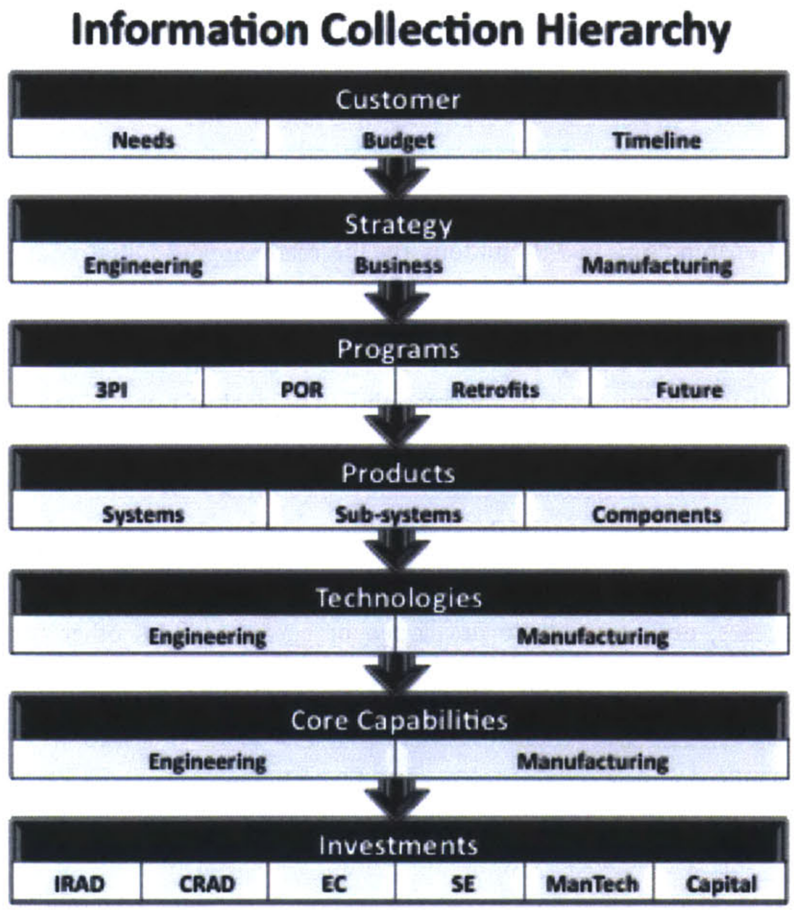

Figure 8: Information Collection Hierarchy at Raytheon SAS

Customer is at the top of the information collection hierarchy. The customers' unmet needs drive the development of new technologies that satisfy those needs. Delivering value to the customer is the ultimate priority and is therefore at the top of the hierarchy.

Strategy determines which of the customer's needs it will satisfy and how it will accomplish this. For technology roadmapping, the engineering, manufacturing and business strategies are particularly relevant, as roadmapping seeks to align and integrate these strategies.

Programs represent the business opportunities that the company has decided to pursue, and can be referred to as the business drivers. Programs represent customer contracts, through which the customer funds the development and/or production of the products to meet their needs. There are four types of programs of interest for the roadmaps: 1) preplanned product improvements (P3I), 2) programs of record (POR), 3) retrofits, and 4) future (speculative) programs.

Products are the physical items that are delivered to the customer to fulfill the requirements of the programs. Each product can be decomposed into a set of systems, sub-systems and components.

Technologies refer to the knowledge and tools that provide the capability to design, develop, manufacture and test the products. Technologies can be physical systems, knowledge, tools, techniques and/or processes. For the purposes of this paper, technologies are classified as engineering or manufacturing technologies, with the engineering technologies referring to the product technologies that will be delivered to the customer and the manufacturing technologies referring to the technologies used for production and testing.

Core Capabilities are the key capabilities that provide the company its competitive advantage. For this project, the core capabilities of interest are those related to engineering and manufacturing.

Investments are the resources allocated for developing the technologies and advancing the core capabilities of the company, to ultimately achieve the company's business objectives.

5.4 Roadmap Architecture

The roadmap architecture provides the framework for "supporting effective dialogue and communication" to serve the objectives of the roadmapping initiative (Phaal & Muller, 2007). It determines how the strategic visions will be aligned and communicated. Understanding the roadmap content, information collection hierarchy and strategic context (need, scope and objectives) provides valuable insight into designing an effective roadmap architecture.

Initially, designing the roadmap architecture seemed relatively straightforward. However, this task actually proved quite challenging due to the many considerations that must be taken into account. Complicating the challenge was the roadmapping team's difficulty in obtaining feedback about the roadmap architecture because of the complexity of designing it. We found that without substantial investment of time and thought, the stakeholders' ability to see below the surface and understand how the architecture would achieve the objectives was limited. Therefore, we received many 'looks great" and "that should work well" responses regardless of the roadmap architecture being proposed. When the roadmapping team thought through the architecture however, we often found that it was flawed and would not achieve the objectives of the roadmap. We found that it was necessary for the roadmapping team to take the lead on designing the roadmap architecture. Building a solid understanding of the strategic context, roadmapping objectives and stakeholders enabled the roadmapping team to take the lead.

Using actual information was useful method for determining the roadmap architecture. Working at a high level of abstraction to design the architecture proved challenging and the most beneficial discussions and progress was made when actual data was used for discussion purposes. The roadmapping team identified a relatively mature program that had required the development of new engineering and manufacturing technologies to satisfy the program and business objectives. With this data and hindsight, the roadmapping team was in a much better position to create the roadmap architecture.

After much thought, the roadmapping team settled on a two-level architecture, consisting of top-level Investment Roadmaps and bottom-level Technology Roadmaps, illustrated in Figure 9. Both the top-level and bottom-level roadmaps consist of engineering and manufacturing roadmaps. Each roadmap provides a different perspective in order to serve different audiences and objectives. Each roadmap provides value individually, but considering all the roadmaps together provides a more complete strategic vision for the management of the company's technology.

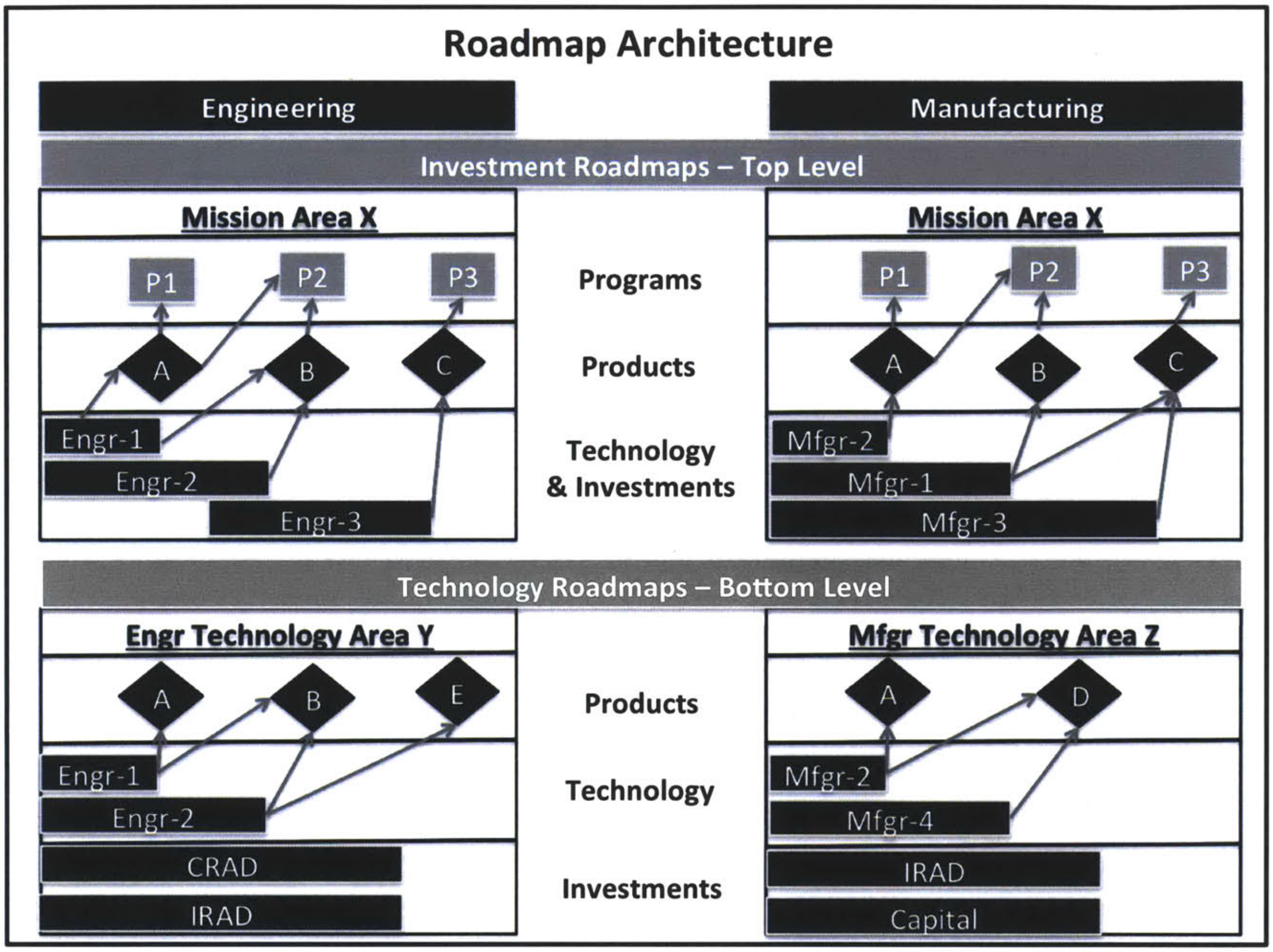

Figure 9: Raytheon SAS Roadmap Architecture

The top-level investment roadmaps have a mission area (i.e., product line) frame of reference frame while the bottom-level roadmaps have technological frame of reference. The top-level Engineering and Manufacturing Roadmaps will align along the same reference frames while the bottom-level Engineering and Manufacturing Roadmaps will align along the different reference frames. As an example, Figure 10 illustrates the different reference frames for top and bottom-level manufacturing roadmaps.

For example, one set (both Engineering and Manufacturing) of top-level roadmaps may focus on Electronic Warfare (the mission area), which crosses several bottom-level technology roadmaps. In the example above, top-level Electronic Warfare roadmap includes information from three bottom-level manufacturing roadmaps. Conversely, the bottom-level manufacturing roadmap, Thin-Film Fabrication spans two Mission Area roadmaps. The relationship between the top and bottom-level engineering roadmaps is similar.

Roadmap Frame of Reference		Mission Area			
		Electronic Warfare	Airborne Radars	Space Sensors	Information Operations
Manufacturing	Thin-Film Fabrication	X	X		
	Laser Assembly			X	
	RF Testing	X	X		
	Circuit Card Assembly	X	X	X	X

Figure 10: Reference Frame Comparison of Investment and Technology Roadmaps

The different perspectives presented by the proposed roadmap architecture are designed for different audiences who will use the roadmaps for different purposes. One purpose of this architecture is to facilitate understanding and acceptance of the different stakeholders by enabling them to contribute from their own perspective. Another purpose is the ability to include more detail in the bottom-level roadmaps. We expect the stakeholders developing and using the bottom level roadmaps will have a more focused perspective and a deeper understanding, hence the desire for more detailed roadmaps.

Relationships between the roadmaps serve to provide a more complete strategic vision, aligning the Engineering and Manufacturing strategies. Although the focus of this project is on the Manufacturing Roadmaps (Manufacturing Investment Roadmaps and Manufacturing Technology Roadmaps), all of the roadmaps, including the Engineering Roadmaps must be considered when designing the architecture. The structure, target audiences and objectives of the roadmaps will be discussed in more detail in the following sections.

5.4.1 Investment Roadmaps (The Top Level)

The top-level Investment Roadmaps strategically align the investments in technologies (engineering and manufacturing) with the business drivers (i.e., the programs). Each Investment Roadmap consists of an Engineering Investment Roadmap and a Manufacturing Investment Roadmap, both aligned along the same business drivers or market (i.e., the top layers are identical).

The Investment Roadmaps link the technologies, products and programs, creating alignment between the technological and commercial perspectives. The roadmaps show the total technology investment required for developing new products and winning new business. The target audience for the Investment Roadmaps is the senior leadership of the company, serving the purpose of guiding the allocation of resources for the development of new technological capabilities aligned with the business objectives. The Investment Roadmaps provide the high-level strategic vision for the alignment of the engineering and manufacturing perspectives and the investment in new technologies, accomplishing the following objectives:

- Align manufacturing, engineering and business strategies to form an integrated strategic vision
- Link technologies to their product and business drivers
- Provide the total investment in technology to win new business and enter new markets
- Facilitate the allocation of resources across the entire technology portfolio
- Coordinate the development and acquisition of technologies
- Create communication channels and information flows for the management of the technology
- Identify, align and advance the company's core capabilities

It is important to note that although we refer to the Engineering Investment Roadmaps and the Manufacturing Investment Roadmaps as separate, they should be thought of as a single document communicating an integrated strategic vision. Ideally, the Investment Roadmaps will be integrated and owned by a cross-functional team in the future.

Engineering Investment Roadmaps

Raytheon SAS develops the Engineering Investment Roadmaps annually and has been evolving the process for a few years now. Currently, there is a total of 23 Engineering Investment Roadmaps and each roadmap focuses on a particular mission area. The purpose of the Engineering Investment Roadmaps is to align the investments in the engineering technologies with the business opportunities.

Manufacturing Investment Roadmaps

The Manufacturing Investment Roadmaps present the high-level strategic vision, serving to align the company's manufacturing technologies with the products and programs. In order to align with the

Engineering Investment Roadmaps, a total of 23 Manufacturing Technology Investment Roadmaps will be created that align directly with the 23 Engineering Investment Roadmaps. The purpose of the Manufacturing Investment Roadmaps is to guide the allocation of resources to accomplish the business objectives and for the advancement of the company's core capabilities.

Investment Roadmap Structure

Timeframe: 5-year outlook

The top layer contains the programs, which represent the business opportunities driving the development of the new technologies (the 'know-why'). Four types of programs are depicted on the roadmaps: 1) preplanned product improvements (P3I), 2) new programs of record (POR), 3) retrofits, and 4) future (speculative) programs. This layer also drives the timing (the 'know-when') for the other layers, since the customers typically set the dates for the key milestones of development programs.

The middle layer contains the products that will deliver the value to the customers by satisfying the requirements of the programs (the 'know-what'). For the Investment Roadmaps, the products are placed on the roadmaps at the time when their maturity has reached a TRL or MRL of 6, for the engineering and manufacturing technologies, respectively. Due to different maturation timelines between engineering and manufacturing technologies, the products' location on the roadmaps with respect to time may differ.

The bottom layer contains the engineering technologies and the Investments (the 'know-how'). The bars represent technology development projects and each project can be decomposed into several technologies that are being developed. However, for the purposes of this paper, we will refer to this layer as containing technologies for clarity. Each bar shows the project's name, the expected duration of the program, the source of funding and the amount of funding. The Investment Roadmaps contain several funding sources including 1) Internal Research and Development (IRAD), 2) Contract Research and Development (CRAD), 3) Selling Expense (SE), 4) Enterprise Campaign (EC), 5) Capital and 6) Manufacturing Technology Grants (ManTech).

Arrows connect the layers, showing the insertion of technological capabilities into the products, and product into the programs.

5.4.2 Technology Roadmaps (The Bottom Level)

The bottom-level roadmaps consist of the Engineering Technology Roadmaps and the Manufacturing Technology Roadmaps, together referred to as the Technology Roadmaps. The Technology Roadmaps are organized different than the Investment Roadmaps, providing a more detailed perspective focused on aligning the investment in technologies to the technological capabilities, which will be tailored for the people developing the technologies.

Unlike the Investment Roadmaps, the top layer (i.e., the drivers) of the Engineering and Manufacturing Technology Roadmaps will not be identical. The topic of each Engineering and Manufacturing Technology Roadmap is the logical grouping of technologies that together make up a set of capabilities. These groupings will differ between the engineering and manufacturing perspectives. The focus of the Technology Roadmaps is to identify technology gaps and determine the maturation timelines and investment requirements to close the gaps. These roadmaps also show all of the investments and technologies that are being developed to advance a core capability. The Technology Roadmaps accomplish the following objectives:

- Link the investments, technologies, capabilities and products
- Identify critical technologies, the gaps and the timelines for development
- Determine the time-phased investments to mature the technologies and close the gaps
- Align development and acquisition of technology to core capabilities
- Facilitate the allocation of resources across the entire technology portfolio
- Coordinate the development and acquisition of technologies
- Create communication channels and information flows for the management of the technology
- Identify technologies that are critical for the advancement of the company's core capabilities

Engineering Technology Roadmaps

Although Engineering Technology Roadmaps are being developed within Raytheon SAS, there is no standard format or procedure for developing these roadmaps. Engineering Technology Roadmaps are outside the scope of this project. However, there is interest within the company in creating standard Engineering Technology Roadmaps and we will briefly propose a structure for the roadmaps in order to provide the complete vision for roadmapping at Raytheon SAS.

Manufacturing Technology Roadmaps

The Manufacturing Technology Roadmaps present a manufacturing perspective and are aligned along manufacturing capabilities (e.g., radio frequency testing facilities, thin film fabrication, circuit card assembly, etc.). Each roadmap represents a set of related capabilities and may include manufacturing technologies from different factories and programs. The intended audience of the Manufacturing Technology Roadmaps is the manufacturing leadership, factory managers and manufacturing engineers.

Technology Roadmap Structure

The top layer contains the products that deliver the particular technological capability. The products will be located on the roadmaps along the time axis at a TRL or MRL of 6 for the Engineering and Manufacturing Technology Roadmaps, respectively.

The middle layer contains the technologies in more detail than the Investment Roadmaps where they are grouped by technology development projects. The Technology Roadmaps will decompose these development projects into the individual technologies that are being, or need to be developed.

The bottom layer contains the investments allocated to the development of technologies. The Technology Roadmaps contain several funding sources including 1) Internal Research and Development (IRAD), 2) Contract Research and Development (CRAD), 3) Selling Expense (SE), 4) Enterprise Campaign (EC), 5) Capital and 6) Manufacturing Technology Grants (ManTech).

Arrows connect the layers, showing the insertion of technological capabilities into the products, and product into the programs.

5.5 Summary

Developing the roadmap architecture creates a common understanding among the stakeholders of what information will be communicated with the roadmaps and how this information will achieve the roadmapping objectives. It facilitates the discussion about the different perspectives and goals of the stakeholders.

Designing the roadmap architecture also encourages the roadmap architects to move from a high level of abstraction to a lower level, as they try to understand what information will be contained and how it will be represented in the roadmaps. Using existing data from a mature program was found to be very helpful in understanding exactly how the information will be represented and communicated within the roadmaps.

6 Development of the Roadmapping Process

Developing the roadmapping process is the final step before creating the roadmaps. The roadmapping process provides the sources and flows of information in order to create the first roadmaps and accomplish the roadmapping objectives.

The main value of roadmapping is derived from the process and not from the product itself (i.e. the roadmaps). The process is the means by which communication channels are formed, information is shared and collaboration occurs. The end product provides value as a shared representation of the common vision developed through the process but should not be the end goal in itself. Focusing on the process will help drive sustainable behavioral changes and provide the means for continuous improvement and evolution of roadmapping. Benefits are gained from developing and executing the process.

Developing the roadmapping process requires participants to think through every aspect of roadmapping, from who will execute specific tasks to who the customers are. The process provides a standard and transferrable framework for implementation and provides a baseline from which the process can be continuously improved.

Executing the roadmapping process forms the necessary communication channels throughout the company and helps drive collaboration among those who should but don't already collaborate. Roadmapping must be a collaborative and iterative effort that should evolve over time in order to realize its full benefits.

6.1 Objectives of the Roadmapping Process

Prior to developing the roadmapping process, it is useful to translate the overall roadmap objectives into objectives for the roadmapping process. The process is the means by which the roadmap objectives will be accomplished and is the mechanism for driving the desired behavioral changes. This follows the thought that most of the value of roadmapping will be derived from developing and executing the process.

Objective #1: Create Manufacturing Roadmaps that will provide the strategic vision to effectively guide the investment decisions for the development of new manufacturing technologies and the advancement of the core manufacturing capabilities. To accomplish these objectives, the Manufacturing Roadmaps should be:

- Easy to understand and contain the pertinent information
- Based on expert consensus and collaboration for accuracy and credibility
- Consistent with the overall company strategy by aligning with the Engineering Investment and Technology Roadmaps
- Used by the decision-makers that allocate the funds and set the operational strategy
- Developed along the appropriate timelines to be included in the relevant decision-making processes

Objective #2: Gain support and participation from the key stakeholders by:

- Involving leadership from Engineering, Technology, Operations and Business Development to set the direction and support the effort
- Respecting the political and cultural landscape of the company
- Forming a roadmapping team that includes advocates from the various organizations
- Addressing the key relevant issues of the organizations to improve performance
- Creating a positive value proposition for all parties involved
- Leveraging leadership support to encourage participation from those without clearly positive value proposition
- Opening up beneficial communication channels that do not currently exist
- Teaching key stakeholders about the benefits of roadmapping
- Communicating motivations and goals of roadmapping, honestly and openly

Objective #3: Produce results quickly to prove-out the value of roadmapping during pilot phases while also maintaining scalability and sustainability for full-scale implementation.

- Develop process that can be implemented in phases, allowing for small-scale pilot
- Process is executable in short timeframe, providing quick learning cycles
- Create a short-term positive value proposition by initially performing much of the work (i.e., reducing the cost of participation for the stakeholders)
- Create roadmaps as soon as possible to secure funding in next budgeting cycle
- Develop a process that does not rely on ad hoc exchanges/flows of information
- Leverage synergistic business processes that provide useful information for roadmapping

Objective #4: Establish valuable communication channels throughout the company to drive cross-functional collaboration by:

- Leveraging existing information flows where they exist
- Establishing communication channels where they don't exist
- Structuring the flow of information so that it is feasible and practical for the communication channels and information exchanges to continue naturally
- Forming a cross-functional Roadmapping Team
- Encouraging communication and knowledge-sharing across factories and organizations
- Changing the culture to value the impact of production on the company's performance
- Incentivizing collaboration between engineering and manufacturing

6.2 Sources of Information

Identifying the sources of information that can provide the content of the roadmaps and accomplish the objectives of the roadmapping process is the next step. The purpose of identifying the information sources is to understand the inputs, outputs and participants for each step of the roadmapping process.

Sources of information consist of individuals and/or groups, as well as company documents and business processes that provide the information necessary for a successful roadmapping initiative. Ideally, the information sources are identified at this time although in reality, the information sources are often difficult to identify at this point. Usually, it is possible to identify the group that should possess some particular information but the actual individual or document possessing the information is more difficult to identify. When searching for a particular type of information, such as the new technologies being developed, the source of the information may reside with individuals with very different job titles and responsibilities. The task of identifying the required sources of information is initially an exploratory process.

For the initial development of the roadmapping process, we identified the sources of information to the best of our ability. Although we initially tried to identify the sources of information based on an individual's position within the company, finding the right people usually was a result of multiple people pointing us toward a particular individual. In other cases, we identified information sources that we believed should possess the information although we were aware that the source did not actually possess the information. In these cases, considering the information that the source requires (i.e., the input) in order to provide the information necessary for the roadmap (i.e., the output) is important. Although generating information is a more challenging task than simply gathering it, the benefits gained by the information source by participating may provide the necessary motivation for that individual.

6.3 Value Propositions for the Stakeholders

Before developing the roadmapping process, it is useful to consider the value propositions for the roadmapping participants. Each stakeholder will be required to contribute some amount of resources to execute the roadmapping process, and in return will realize some amount of benefit. Comparing the benefits and costs of each stakeholder can provide a better understanding of how the stakeholders might react to a proposed process.

As part of the stakeholder analysis, the benefit and cost for each stakeholder was considered in order to anticipate the willingness to participate in the effort. Expanding on this thought process and considering the knowledge gained since the stakeholder analysis provides insight into the value propositions for each stakeholder. Another important aspect to this thought framework, is each stakeholder's timeline of incurring these costs and benefits. Similar to a discounted cash flow analysis, the value of any benefit is discounted by the amount of time required to realize the benefit. If the too much time elapses after a participant's initial investment of resources, it is unlikely that they will be willing to contribute, either initially or in the future. Figure 11 provides an illustrative example of the output of such an analysis.

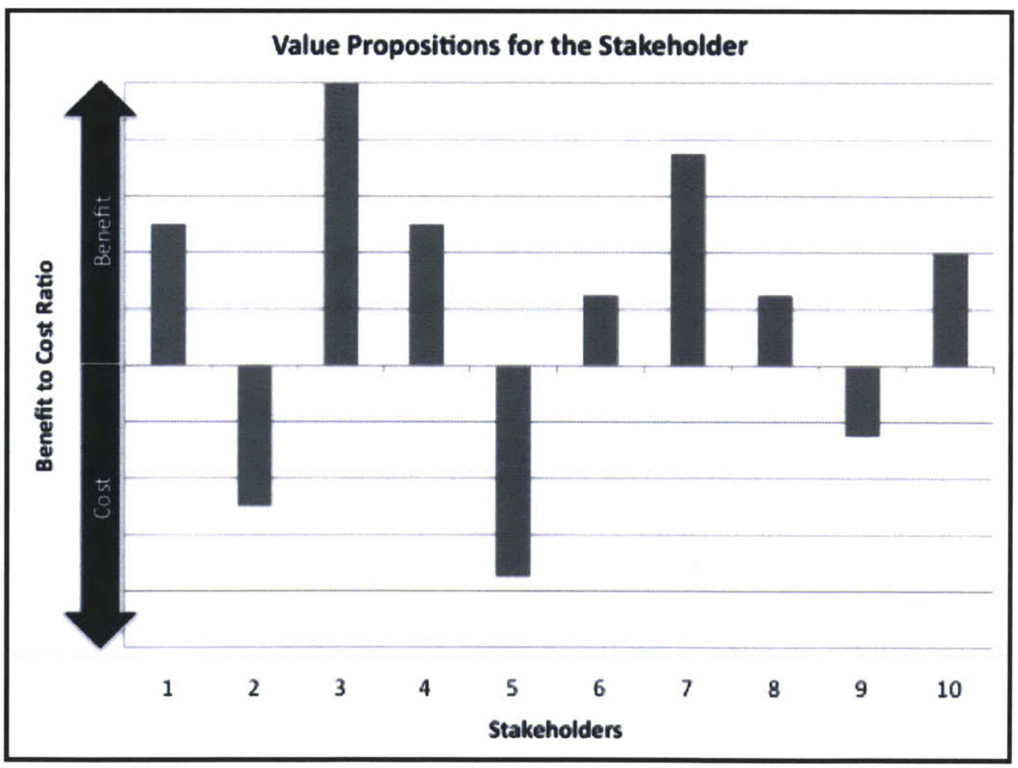

Figure 11: Value Propositions to the Stakeholders

6.4 The Proposed Process

Several processes were proposed and considered for roadmapping the manufacturing technology at Raytheon SAS. The culture and politics of the company, the available resources, and the organizational structure ultimately determined the process chosen.

Initially, a workshop-based roadmapping process was investigated, similar to that proposed by Phaal et al. (2007). The goal of this approach was to gain broad participation as early as possible and to facilitate cross-functional collaboration. However, several factors impeded the initiation of a workshop-based approach. Conducting large cross-functional workshops at this early stage exposed the initiative to much risk, as the failure of the initial workshop could result in the failure of entire initiative. One main reason that the workshop might fail is that the knowledge of the manufacturing technologies is lacking, meaning that the information must be developed before it can be captured, shared and aligned. Developing the required knowledge about the manufacturing technologies requires ongoing collaboration and communication between engineering and manufacturing, as the design changes frequently during the early phases of technology development. Another reason is that the nature of the business requires barriers to freely sharing information due to security and competitive concerns. Another reason is that participants may be hesitant to share information for reasons of internal competition. Openness with information and perspectives is important for the success of a workshop-based approach and we decided that pushing this approach would not lead to a desirable outcome. There is also a lack of confidence and consensus that the right participants for roadmapping have been identified, which is a critical factor in conducting a successful workshop. Finally, only limited resources are initially available and conducting a series of workshops exceeds the budget.

These concerns led the roadmapping team to consider other processes for developing the roadmaps, whereby the initiative could gain more momentum and continue to improve its chances of success. The proposed process focuses on the roadmapping team taking the lead, engaging the participants individually or in small groups. The roadmapping team transfers the relevant information from one participant to another, driving the flow of information through the company. The roadmapping team will also connect individuals and groups when collaborative engagements are necessary. The main reason for choosing this process is the expectation that much of the information required for the roadmaps is unknown due to a lack of cross-functional communication and collaboration across the company. The proposed process enables the roadmapping team and participants to obtain the information necessary to develop the information contained in the roadmaps. Another reason is that strategic information is considered very sensitive and people are reluctant to share the information, even with others inside the organization. Small group meetings are more conducive to openly sharing information, once trust has been built. They are also shorter, more frequent and easier to schedule, requiring less resources and commitment from the participants. Another reason is that it allows the roadmapping team to continue to explore and find the right participants without exposing the initiative to a highly visible failure that could occur if the workshop did not involve the right people. The roadmapping process focuses on driving the communication and collaboration necessary to develop the knowledge for the roadmaps.

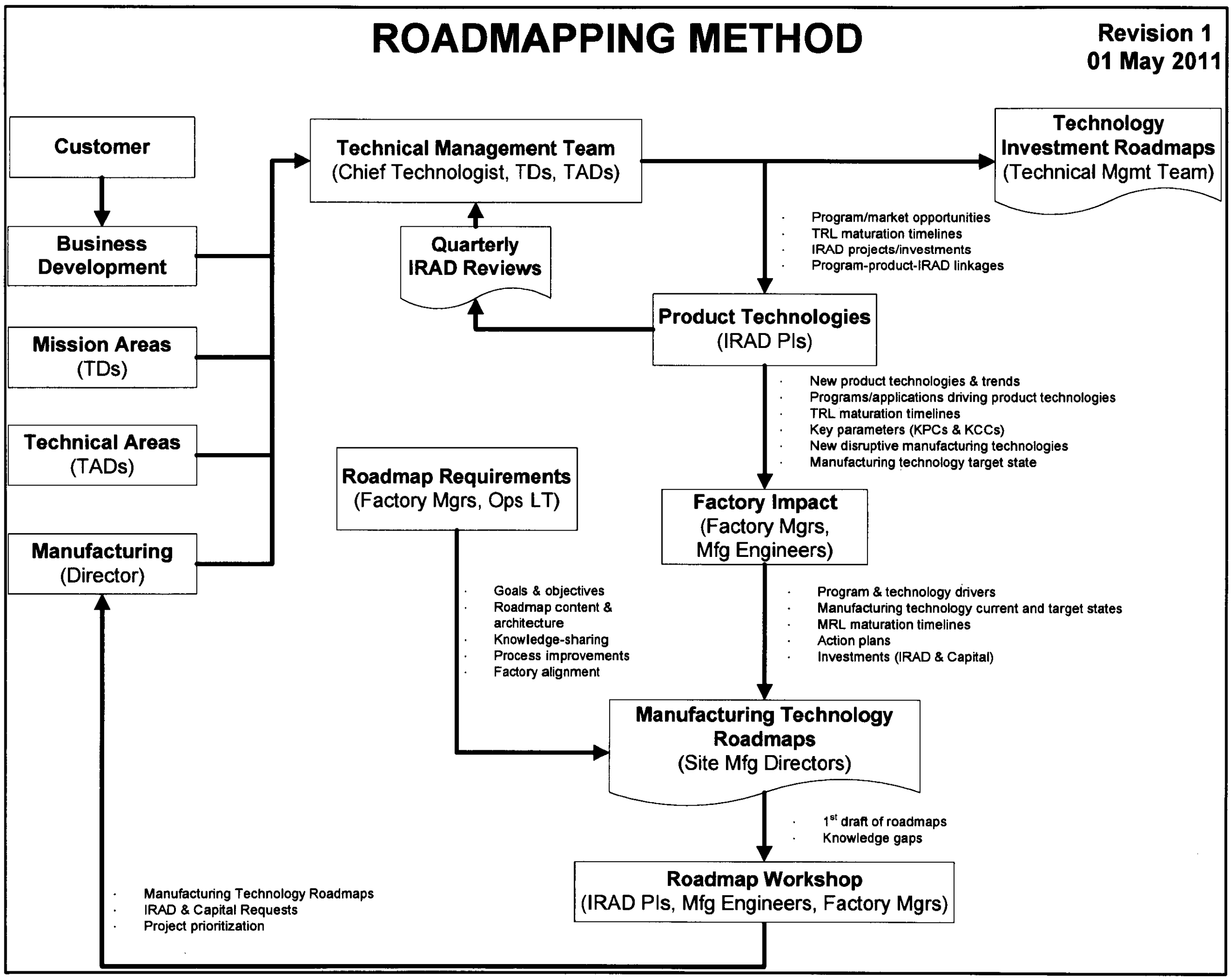

Figure 12: Proposed Process for the First Roadmapping Cycle

Figure 12 provides an overview of the proposed roadmapping process and each activity is described below. The roadmapping process describes a process for creating Manufacturing Roadmaps and is meant to be iterative. The proposed process is for the first iteration of the roadmap development, providing a baseline for the process to evolve and improve over successive iterations. The scope of the first roadmaps is more focused and will eventually expand to cover the entire scope and accomplish all of the objectives.

For the first iteration, the process will focus on the manufacturing technologies being driven by the development of new product technologies, particularly those being developed in IRAD programs. The IRAD programs are funded by the company and the effective allocation of these resources, guided by the Engineering Investment Roadmaps, is a high priority. IRAD funds are also a likely source of money for the development of new manufacturing technologies.

Another reduction in the scope of the first roadmaps is the consideration of internal manufacturing technologies only. Outsourced manufacturing technologies will not be considered beyond identifying the need for the technologies but current and target states of the external technologies will be left for the next roadmapping iteration.

Activities of the Roadmapping Process

This section will discuss the purpose and participants of each of the roadmapping activities illustrated in Figure 12.

Roadmap Requirements – The goal of the Roadmap Requirements activity is to establish and update the goals and objectives of the manufacturing roadmapping initiative. It also serves to facilitate communication and knowledge-sharing across the factories and manufacturing organization. This activity creates and updates the vision for the manufacturing roadmaps.

Technical Management Team & Investment Roadmaps – The Raytheon SAS Technical Management Team consists of Business Development (BD), Technical Directors (TDs) and Technical Area Directors (TADs) from across the entire company, each contributing different perspectives and knowledge. The Technical Management Team synthesizes and aligns these perspectives and knowledge to develop the Engineering Investment Roadmaps that communicate the strategic vision and guide the investments for the development of new engineering technologies. The Engineering Investment Roadmaps facilitate the selection of the IRAD programs for funding and align the investment decisions to the business drivers. As part of the manufacturing roadmapping initiative, Technical Directors from manufacturing have recently joined the Technical Management Team in order to align the Manufacturing Investment Roadmap with its Engineering counterpart. Once the Manufacturing Investment Roadmaps have been developed, they will serve a similar purpose, aligning the manufacturing technology investments with the engineering technologies and business drivers.

IRAD Programs – After funding has been allocated, the Principal Investigators (PIs) of the funded IRAD programs lead the development of the new engineering technologies. The Engineering Investment Roadmaps provide the PIs the strategic vision to understand how their program fits into the bigger picture, communicating the business drivers and maturation timelines. This strategic vision is also important for the Manufacturing Investment Roadmaps in identifying the engineering technologies and assessing the manufacturing impact of those developments. The IRAD programs provide quarterly reviews to the Technical Management Team, in order to assess the progress and maintain alignment.

Factory Impact – Information about the product technologies being developed is communicated to the factory managers and manufacturing engineers who will assess the manufacturing impact to the factories. Assessing the factory impact means understanding the drivers of new manufacturing technologies, identifying the manufacturing technologies and gaps, creating action plans to mature the manufacturing technologies along the appropriate timelines and requesting funding for the development and acquisition of new manufacturing technologies. The factory impact translates the engineering technologies into manufacturing technologies. This is one of the most critical and difficult activities of the process, as it will provide the detailed description of the future state of the manufacturing technologies.

Manufacturing Roadmaps – The Roadmap Requirements and the Factory Impact activities provide the knowledge necessary to create the Manufacturing Roadmaps. The Factory Impact activities provide the detailed knowledge of the current and future state of the manufacturing technologies, the maturation timelines and the investment requirements. The Roadmap Requirement activity provides the strategic vision that aligns the manufacturing technologies with the business drivers and manufacturing strategy.

Roadmapping Workshop – The final activity of the roadmapping process is to conduct a Roadmap Workshop, which brings together key stakeholders from Engineering and Manufacturing to validate the roadmaps and ensure there is alignment. This activity also provides a feedback loop to the IRAD PIs about the manufacturing impact of the engineering technologies being developed. The validated roadmaps can then be used to prioritize the technologies and allocate the resources for their development.

6.5 Summary

The proposed process was designed to accomplish the objectives of the roadmapping process, while also considering the environment in which the process will be executed. Although the execution of the roadmapping process will still be an exploratory endeavor, the process of developing the process proved to be valuable. Identifying the right people is still a key factor to the success of the roadmap that will only be resolved during the development of the roadmaps.

Developing the process required the roadmapping team to synthesize all of the knowledge gained thus far in the project and to think through the tactical issues of developing the roadmaps. Understanding the information flows, communication channels and collaborations that are necessary to deploy roadmapping is useful in identifying the instances where this is not happening. The goal of the proposed roadmapping process is to accomplish the roadmapping objectives, learn from the experience, build support and create roadmaps in order to ensure that the roadmapping initiative is alive for the next iteration.

7 Development of the Roadmaps

The development of the roadmaps requires executing the proposed roadmapping process to develop the first draft of the Manufacturing Roadmaps. Executing the process is expected to identify both the successes and failures of the proposed process and provide valuable lessons that can be used to improve the process for future roadmapping cycles. The creation of roadmaps will also serve to prove out the value of the roadmaps to build support within the company.

In this chapter, selecting the subject of the first roadmaps and the development of the roadmaps is discussed. The success and the failures will be presented, and how the initiative was adapted and evolved to address these successes and failures will be discussed. Finally, a revised process is proposed for the next roadmapping cycle and the Manufacturing Roadmaps are presented.

7.1 Selecting the Roadmapping Pilot

To select the subset of the business that will be the focus of the roadmapping pilot, several factors were considered. The factors impact the ability to execute the proposed process and the potential value delivered to the company. The factors to consider are:

- Strategic value of the technologies chosen
- Complexity and innovativeness of the manufacturing technology
- Factories involved in the production of the technologies
- Alignment with Engineering Investment Roadmaps
- Access to people and information
- Internal support within the proposed area

For the first roadmapping cycle, the roadmapping team decided to focus on developing a Manufacturing Investment Roadmap for 'Market A', aligned to an Engineering Investment Roadmap for the same market, and the associated Manufacturing Technology Roadmaps. Raytheon has deemed 'Market A' an important strategic objective that presents several new business opportunities for the company. The development of new product technologies for this market will also drive the development and acquisition of new manufacturing technologies. Because the Investment and Technology Roadmaps are aligned along different perspectives, multiple Manufacturing Technology Roadmaps will be created that each provide a more-detailed view of the manufacturing technologies contained in the Manufacturing Investment Roadmap, as well as manufacturing technologies not included in the Manufacturing Investment Roadmap.

7.2 The Revised Process

Executing the roadmapping process provides a valuable learning experience for the roadmapping team, stakeholders and participants. As expected, it proved to be an exploratory process, encountering both successes and failures. All of the expended effort prior to the development of the roadmaps provided valuable insight for this phase of the roadmapping initiative though. The understanding of roadmapping and the strategic context developed in the previous activities enabled the roadmapping team to adapt on the fly and continue to make progress. The roadmapping process was adapted during the development of the first roadmaps and the revised process is shown in Figure 13.

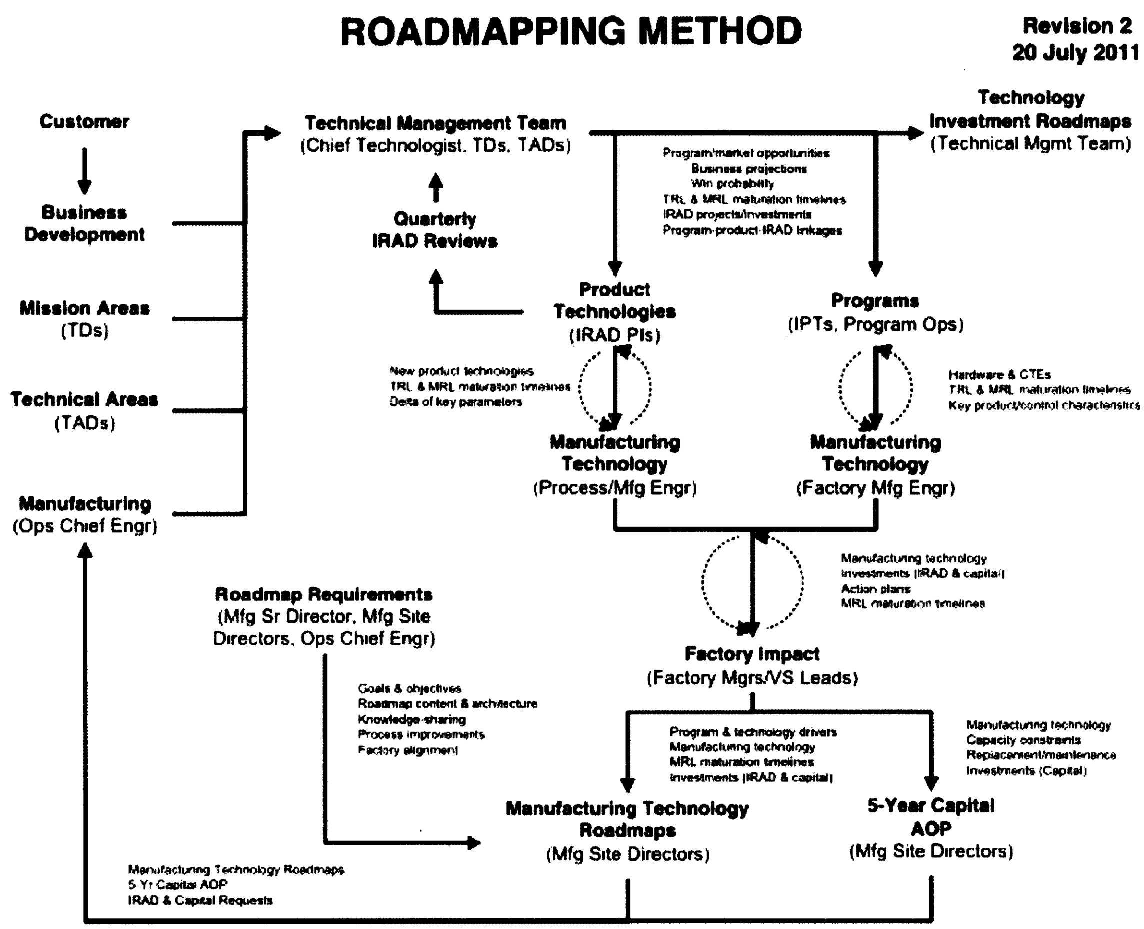

Figure 13: Revised Process for the Next Roadmapping Cycle

The revised roadmapping process incorporates the knowledge gained from the first roadmap cycle and serves as a starting point for the next roadmap cycle. Important considerations for the development of the next roadmaps are discussed below.

7.2.1 Expand scope to include all manufacturing technologies

The roadmapping team's decided to limit the scope of the first roadmapping iteration in order to focus the effort and produce results quickly. The drivers for the development of new manufacturing technology at Raytheon SAS are the engineering technologies and products, and determining which of those technologies will be developed internally is dictated by the manufacturing strategy. Our attempt to limit the scope focused the team's efforts on the manufacturing technologies that will:

- Be driven by product technologies being developed in IRAD programs
- Deliver new technological manufacturing capabilities to the company
- Represent a key manufacturing technologies
- Developed internally, most likely

Although some focus is necessary, the challenge of trying to classify a particular technology in order to decide whether or not it should be included in the roadmaps as a new capability presented more difficulties for the execution than it did for the benefits in scope reduction. A manufacturing technology may increase capability, expand capacity and reduce cost simultaneously and confining it to one classification may not make sense. Because the engineering and manufacturing technologies align along different reference frames and because Raytheon competes on its products, including as many manufacturing technologies as practical will provide a more complete picture and may prove less challenging.

Focusing on only the manufacturing technologies being driven by the product technologies of the IRAD programs proved particularly challenging. IRAD programs are often tasked with developing the most innovative and immature technologies that will be inserted into products further in the future. One implication is that assessing the manufacturing impact of these technologies is difficult, due to the uncertainty in the design at this stage of development. Another implication of only considering the engineering technologies being developed in the IRAD programs is that the systems, sub-systems and components of the products also drive the development of new manufacturing technologies are not considered. Roadmapping the manufacturing technologies being driven by the IRAD programs proved challenging and provides only a part of the desired vision. Therefore, the roadmapping process adapted to consider the manufacturing technologies that are driven by new tighter specifications of products, as well as new engineering technologies. This could be further expanded to all manufacturing technologies, whether it provides capability improvements, capacity expansions and/or cost reductions.

7.2.2 Roadmapping is not a technique for generating information

Lack of data and information is the most-cited barrier to success for roadmapping initiatives (Phaal R. , Technology Roadmapping, 2003) and proved to be the greatest challenge hindering roadmapping at Raytheon SAS. Throughout the project, the lack of information resulted from the information that was not known, available or yet found. The unknown information was often the result of a break down in cross-functional collaboration or processes that should develop this information. The unavailable information was typically the result of proprietary/confidentiality concerns. And some of the information had just not yet been found because the right people had not been engaged or the right documents had not been located. However, by the end of the project, it was apparent that much of the information does not yet exist, which poses a significant challenge for the next roadmapping cycle.

Roadmapping is an effective tool for sharing, capturing and aligning information for developing and communicating the strategic vision, and for allocating investments. It is not the best method for developing information, such as the manufacturing technologies that are required for a particular product being developed. Cross-functional collaboration and communication is critical for developing the detailed information required for roadmapping, but roadmapping is not the appropriate tool to generate this information. This information is better developed through cross-functional product development teams and technology and manufacturing readiness assessments (T&MRAs) during the Identification & Monitoring phase of technology management and is an input to roadmapping. Roadmapping uses this detailed information to facilitate cross-functional collaboration, communication and alignment at a strategic level.

The Engineering and Manufacturing collaboration at Raytheon SAS varies between the extremes, with collaboration occurring very consistently at some sites and not at all at others. The availability of the information needed for roadmapping correlates well with the amount of collaboration. In the cases where the detailed information was undeveloped, we used roadmapping in an attempt to force this collaboration. Although we found some success in developing the information, the most valuable and accurate information was collected in the cases where the cross-functional collaboration was already occurring, frequently and consistently. Cross-functional collaboration is a common challenge facing many companies, including Raytheon SAS.

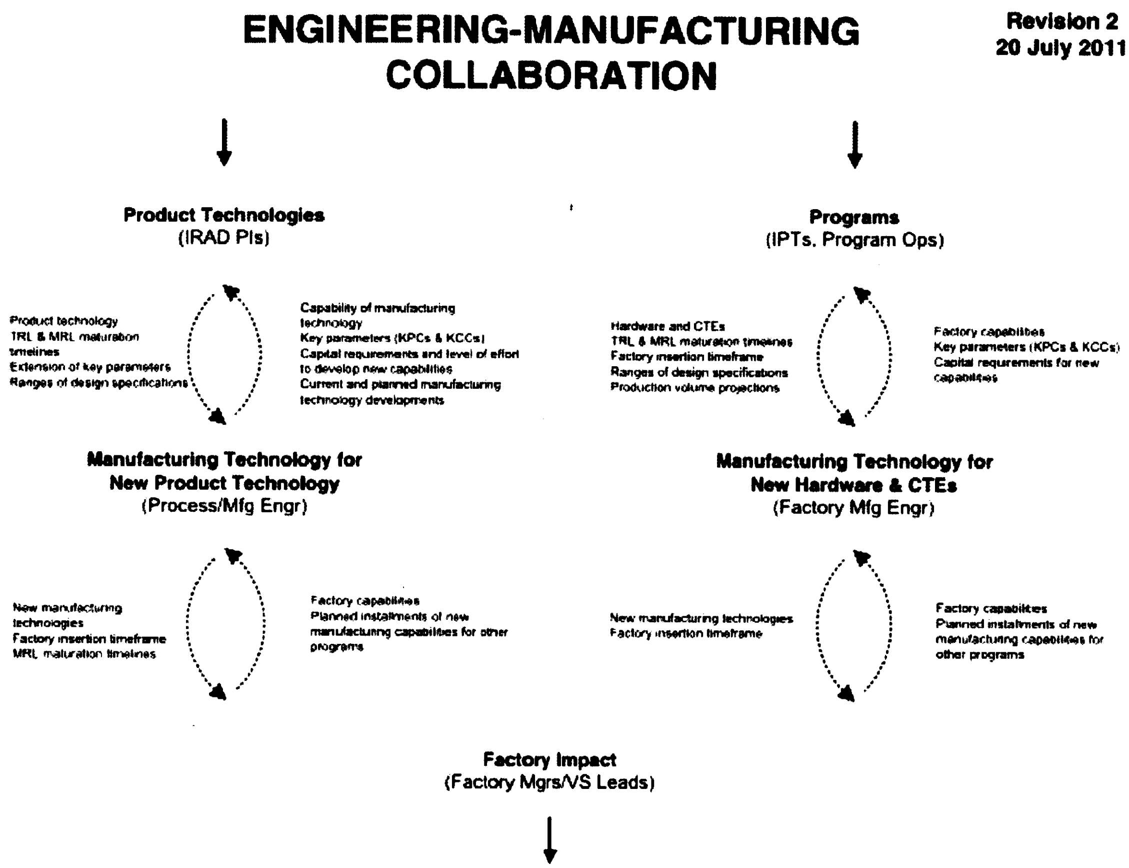

Figure 14: Collaboration between Engineering and Manufacturing

Figure 14 illustrates the collaborative information exchanges between engineering and manufacturing that should exist and provide the information input to the roadmapping process. Although the roadmapping process attempted to drive this collaboration to generate the information necessary for roadmapping, other tools and processes would better serve this task.

7.2.3 Engage many people quickly and openly

Finding the participants with the necessary perspective and knowledge proved to be one of the most challenging aspects in the development of the roadmaps. Convincing that person to dedicate some of his scarce time to roadmapping was almost as challenging.

For the initial development of the roadmaps, participants were identified from the Raytheon SAS's organizational chart. Although the correct function, business unit or department for the information sought after was typically identified, finding the right person was more challenging. Typically, the person that could provide the perspective and knowledge required for the roadmapping initiative was identified after references from several other people. Take the time to engage as many people as possible, inform them of the objectives of roadmapping and the information being sought after, and eventually the right people will accrue the most references. The other purpose for engaging a broad audience early on is that the perspectives of everyone within a company is limited in some way. Understanding as many perspectives as possible prevents the roadmapping team from arriving at incorrect conclusion or misguided perceptions. The limited number of people engaged initially hindered the progress of the initiative. In fact, it was not until many people were contacted that the right people were identified and brought on board. Building a broad network quickly is important for the success of roadmapping.

Almost as important is building trust through open communications with people during engagement. A trusting relationship is important for understanding the needs for roadmapping and obtaining the information for the roadmaps. Roadmapping requires substantial effort from a broad group of participants, and without the participants' trust, it is unlikely that the roadmapping team will receive the participation necessary for success.

As expected, identifying the right people is critical for a successful roadmapping outcome. Once the right people are engaged however, they were often able to provide a wealth of information. It is essential that these people be identified and relationships are formed as soon as possible.

7.3 Manufacturing Roadmaps

The two-level roadmap architecture for the Manufacturing Roadmaps proved to be an effective architecture, as it enabled participants to provide information from the normal perspective. The architecture encouraged the participants to contribute information about the new technologies and investments.

The information gathered and developed through the execution of the roadmapping process varies between different programs, factories and people. The information varied with respect to the amount, the level of detail, the terminology, the format and the organization. Due to this variability, the structure of the roadmaps had to adapted. As the initiative evolves and participants become more familiar with the technique, the information is expected to be more readily available and consistent.

The initial goal of the pilot was to create one Manufacturing Investment Roadmap and at least one Manufacturing Technology Roadmap. All together, two Manufacturing Investment Roadmaps and nine Manufacturing Technology Roadmaps were developed. Together, these roadmaps represent about one-quarter of Raytheon SAS's manufacturing technologies. Once the right people were involved and the participants gained a better understanding of roadmapping, the momentum of the initiative and the amount of information gathered continued to increase.

7.3.1 Manufacturing Investment Roadmaps

The Manufacturing Investment Roadmaps provide the strategic vision for allocating investments for the development of Raytheon SAS's manufacturing capabilities. It also aligns the development of the manufacturing capabilities to the engineering capabilities in order to achieve the business objectives.

Figure 15 shows an example of the Manufacturing Investment Roadmaps developed. Comparing it to the Engineering Investment Roadmap in Figure 16 shows the alignment of the Investment Roadmaps along the same business drivers. Together, the Manufacturing and Engineering Investment Roadmaps provide a complete picture of the investment requirements for the development of technologies and products to enter Market A and win new programs.

The top layer contains the programs and is identical to the top layer of the Engineering Investment Roadmap. The programs represent the business drivers for the development of new technologies. The top layer also contains dark and light blue lines that serve to highlight major strategic business objectives of this market.

The middle layer shows the products that will deliver the technologies to the programs. Products are located on the roadmaps at a time when they must be at a MRL of 4 and/or 6, depending of the requirements of the program driving the development of the product. MRL 4 and 6 represent two milestones in the maturation of manufacturing technologies (refer to Appendix A). Arrows link the products and programs, showing the products delivered to each program. For clarity, some of the arrows have been removed, leaving the most important linkages obvious. The colors of the arrows highlight the linkage between the products and the major strategic business objectives.

The bottom layer contains the manufacturing value streams and investments, divided up by factory value streams. Each factory value stream represents a high-level manufacturing capability. For each value stream that is impacted by the products of the roadmap, the amounts and sources of funding required to develop the manufacturing capabilities are shown. The IRAD, CRAD and Capital provide the expected funding amount from each source. An unplanned addition to the funding sources is the MRL Gap funds, shown in red, which represents the current funding gap to mature technologies from MRL 4 to MRL 6. This gap was found to be an important gap that deserves to be highlighted in the roadmaps. The colored block arrows link the manufacturing capability and investments to the products and programs driving them.

Timeframe – Five years

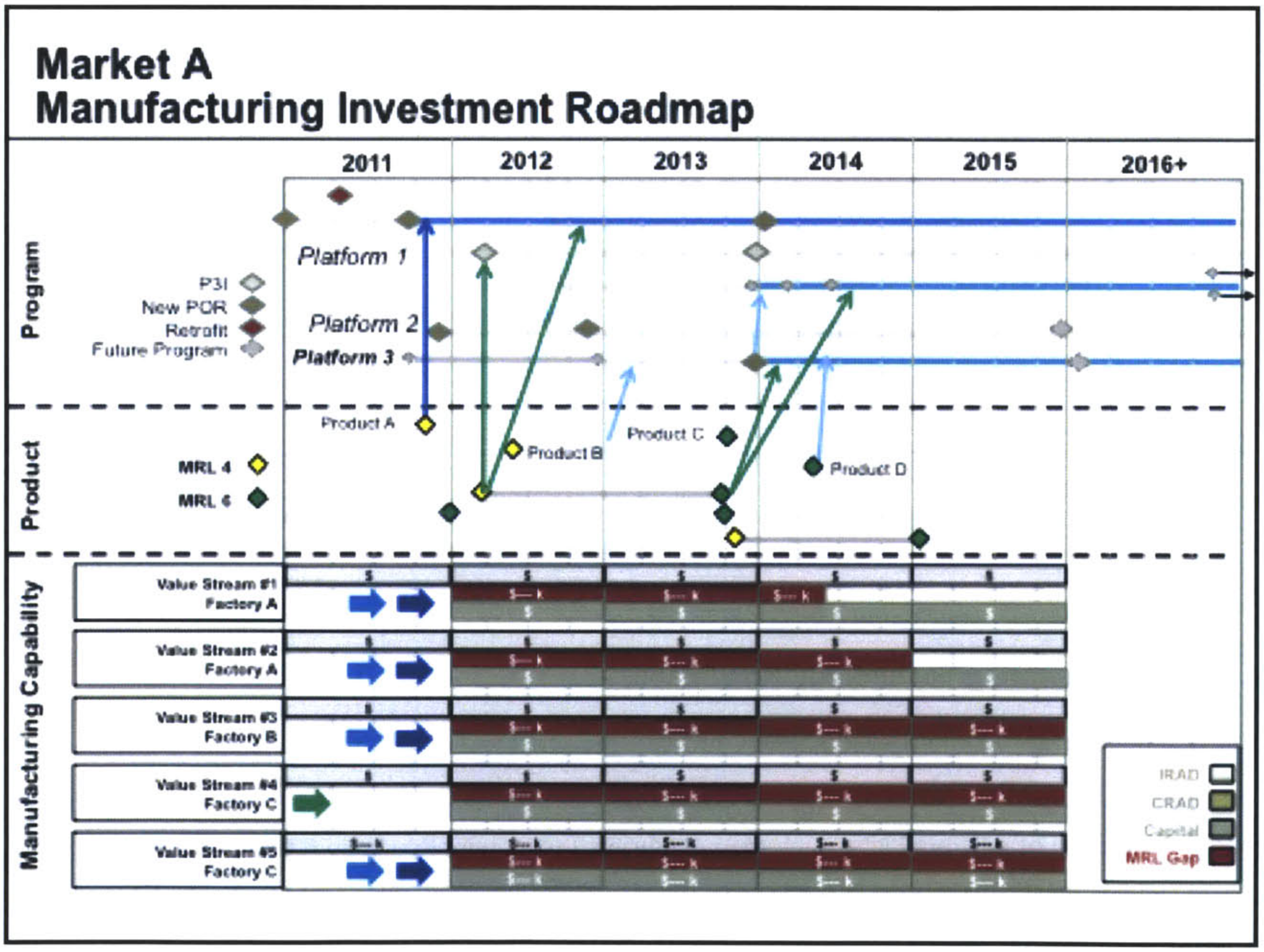

Figure 15: Example of a Raytheon SAS Manufacturing Investment Roadmaps

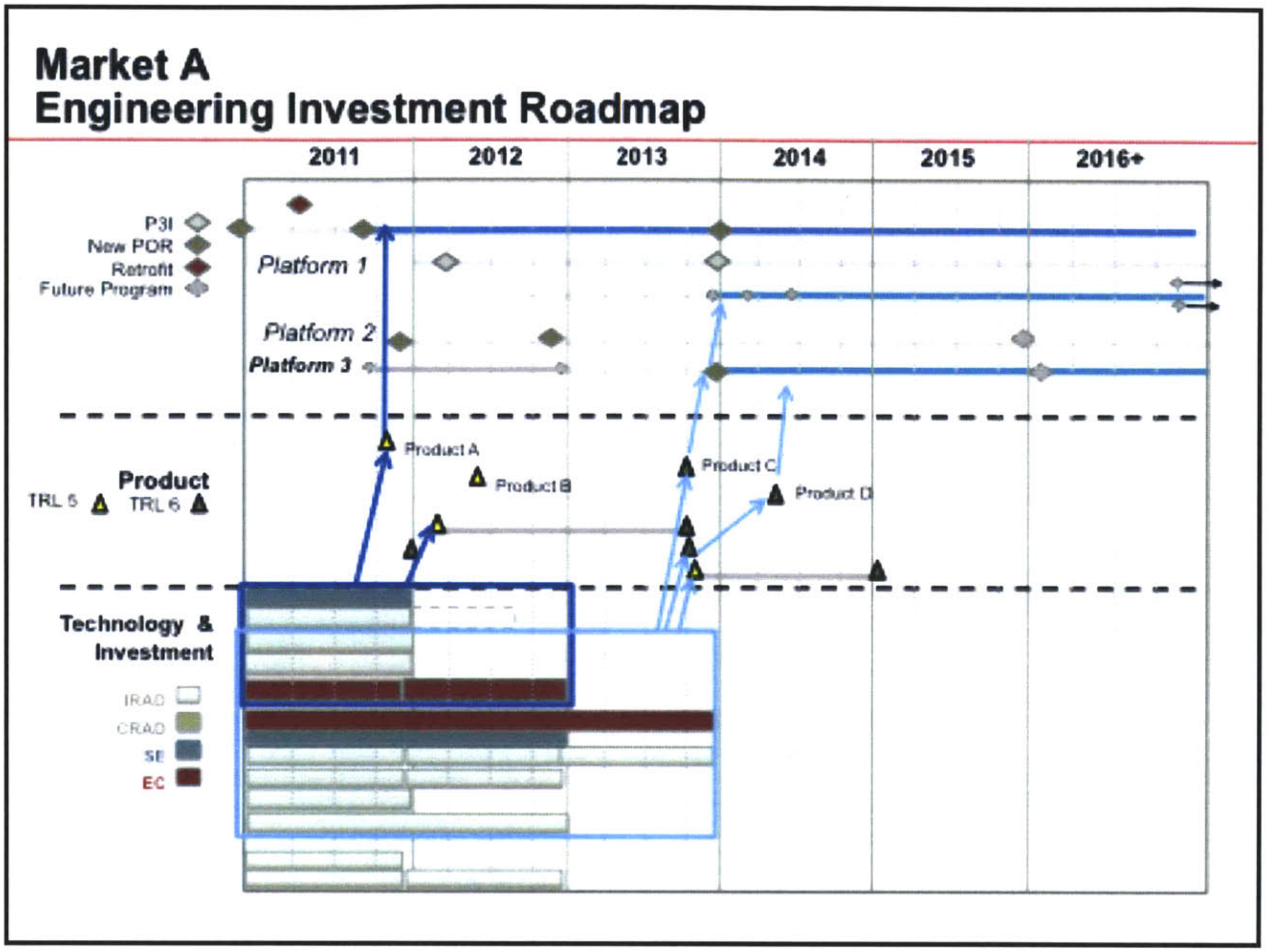

Figure 16: Example of a Raytheon SAS Engineering Investment Roadmap

7.3.2 Manufacturing Technology Roadmaps

The Manufacturing Technology Roadmaps provide the strategic vision from a factory's perspective, showing the timelines for investing in and developing manufacturing technologies in order to be prepared for the production of new products. Each Manufacturing Technology Roadmap represents a factory value stream, which represents a high-level manufacturing capability of Raytheon SAS. Each value stream typically manufactures several products that span more than one market.

Figure 17 shows an example of the Manufacturing Technology Roadmap for Value Stream #1 at Factory A. Referring back to the Manufacturing Investment Roadmap in Figure 15 shows the link between the Manufacturing Investment and Technology Roadmaps. The Manufacturing Investment Roadmap aggregates all of the manufacturing technology and investments in Value Stream #1 at Factory A that relate to the products in the several Manufacturing Investment Roadmap, including the Investment Roadmap for Market A.

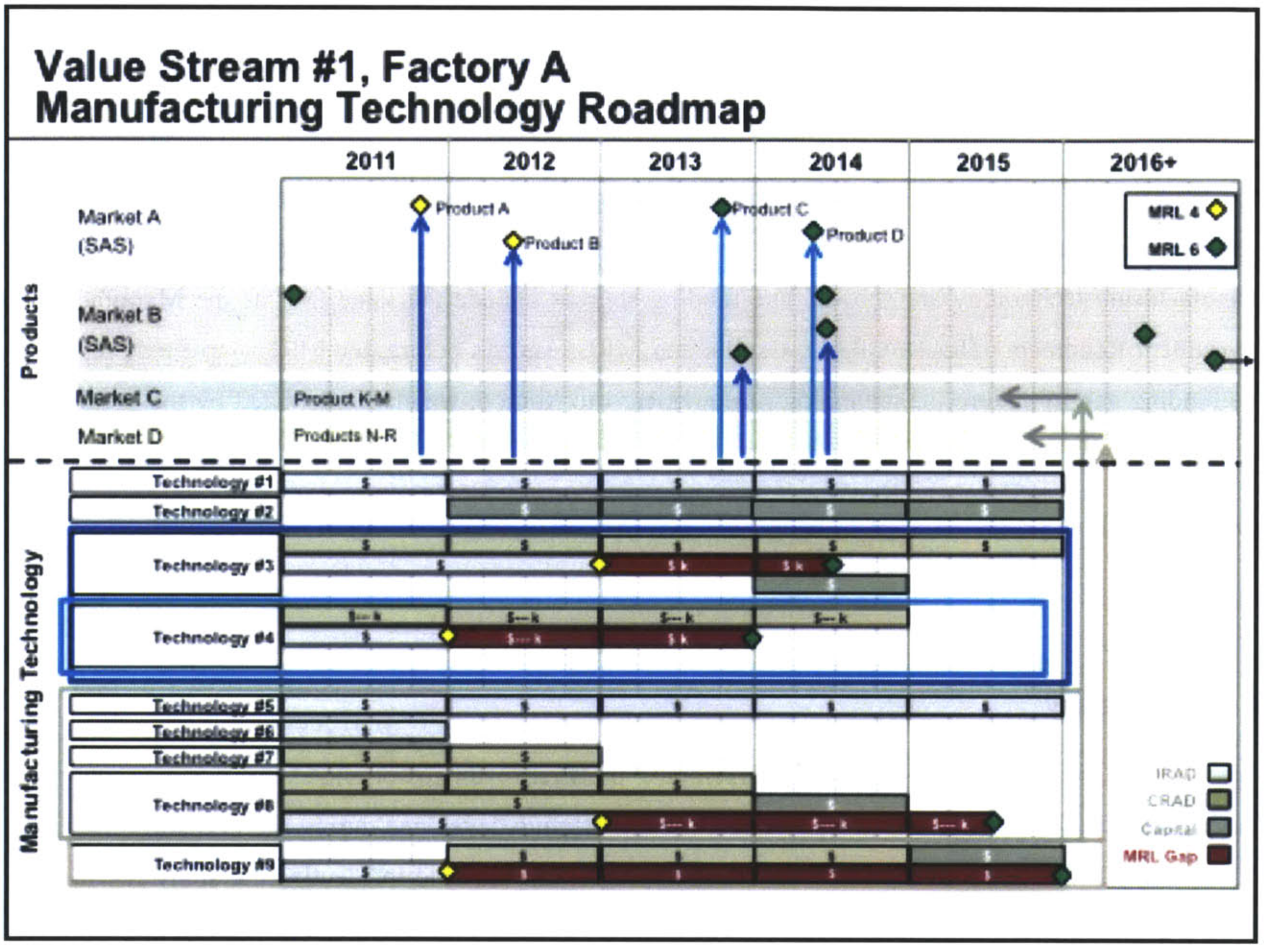

Figure 17: Example of a Raytheon SAS Manufacturing Technology Roadmap

The top layer contains all of the products that are manufactured in part or entirety by Factory A's Value Stream #1. The products span four markets (i.e., Investment Roadmaps) and three Raytheon businesses (SAS, RMS and IDS), showing the different alignment of manufacturing and engineering perspectives. As in the Manufacturing Investment Roadmaps, the products are shown when they are required to matured to a MRL 4 or MRL 6, depending on the requirements of the program.

The middle layer, which was to contain the manufacturing capabilities was removed for two reasons. First, the Manufacturing Technology Roadmaps of each value stream each represent a high-level manufacturing capability. The original plan was for the Manufacturing Technology Roadmaps to span all the factories' value streams that provided a relevant capability in order to coordinate technologies across the factories. Although this cross-factory coordination may be beneficial, it proved to be prohibitively difficult for the first iteration. After all of the Manufacturing Technology Roadmaps have been developed, the roadmapping team should review the roadmaps for redundancy and overlap. For the first cycle though, aligning the manufacturing technologies with the engineering technologies was deemed most important and the coordination across value streams was saved for another roadmapping cycle.

The bottom layer contains the manufacturing technologies and investments that collectively deliver the manufacturing capability of the value stream. The investments and maturation timelines for each manufacturing technology are shown. The funding sources include the same four as the Manufacturing Investment Roadmap – IRAD, CRAD, Capital and MRL Gap. As before, the MRL Gap funds represent the funding gap to mature the technology from MRL 4 to MRL 6, which are depicted by the yellow and green diamonds, respectively.

Timeframe – Five years

7.4 Summary

Executing the roadmapping process and developing the first roadmaps provided the roadmapping team the critical experience of testing the processes and architecture developed during the initiation phase and it was only after this experience that the roadmapping team was able to identify the shortfalls in their thought processes. In addition to the benefit gained by roadmapping team, it also greatly increased the level of support within the organization. As stakeholders were engaged, it became clear to them that the roadmapping team had done their homework and the initiative had a good chance of success. As stakeholders gained access to important information necessary to improve their strategic vision, they realized the benefits of roadmapping. Although the importance of the initiation phase has been stressed, and rightfully so, there is no substitute for the benefits gained from doing.

8 Conclusion

The goal of the project is to initiate roadmapping of the manufacturing technology at Raytheon SAS. To accomplish this goal, the roadmapping team researched the topics of technology management, roadmapping, organizational change, dynamics of process improvements, manufacturing operations, new product development, and leadership to develop a solid understanding of the factors involved and develop a roadmapping process appropriate for Raytheon SAS. The process focuses on the initiation and development phases of roadmapping in order to create a sustainable and continuously improving roadmapping process that drives positive behavioral changes across the company. Two of the greatest challenges for a successful roadmapping initiative are its initiation and the development of a robust roadmapping process. This project seeks to overcome these challenges while also creating a strong foundation of knowledge and support to overcome the single greatest challenge, keeping the roadmapping initiative alive.

8.1 Key Findings and Recommendations

The project provided many valuable insights into the challenges and success factors of roadmapping. While the findings and recommendations are the result of a project at Raytheon SAS, the author believes these lessons are applicable to any company wishing to implement manufacturing technology roadmapping.

8.1.1 Roadmapping drives behavioral change

Roadmapping can drive positive behavioral changes by focusing on the process and not the product. The majority of the value of roadmapping is derived from the process of roadmapping and not the products (i.e., the roadmaps). The roadmaps represent a shared representation of the stakeholders' strategic vision, but the process of developing this vision through the sharing and alignment of the stakeholders' knowledge and perspectives provides the understanding needed to develop and deploy the strategy. The roadmapping process needs to be designed in order to drive sustainable behavioral changes.

8.1.2 Understand the applications and limitations of roadmapping

Technology roadmapping is a powerful and effective technique for capturing complex and interconnected information, for aligning different perspectives, for developing and communicating a strategic vision and for allocating investments. However, it is not an all-encompassing universal tool for solving every challenge of technology management. Throughout the project, it was not uncommon for stakeholders and participants to want to apply roadmapping to address issues outside of the capabilities of roadmapping. It is important to understand the applications and limitation of roadmapping and to use the tool appropriately. Other tools are more effective for the other stages of technology management.

8.1.3 Initiate the proejct wisely

The efforts of the roadmapping team leading up to the development of the roadmaps proved to be valuable during the execution of the roadmapping process. The knowledge and insight gained during the initiation phase of roadmapping provided the foundation and ability to adapt the roadmapping process during its execution and the roadmap architecture during its development. Equally important, the initiation phase built the support necessary to allow the roadmapping process to be implemented in the first place.

8.1.4 Explore and iterate quickly to show the value of roadmapping

Although the initiation phase is important and is a prerequisite for developing a roadmapping process and creating roadmaps, it is important to understand the value of the roadmap development phase. It is during this phase that the stakeholders really begin to perceive the value, as the information begins to flow and the roadmaps start taking shape. Allowing the stakeholders to see the benefits of roadmapping will build support within the company and the next roadmapping iteration will reap the benefits of greater commitment, participation and understanding. The goal of the first roadmapping iteration should be quick execution, not perfection.

Roadmapping is initially an exploratory process, whereby many stakeholders and participants collaborate and share knowledge to arrive at a common vision. During the early phases, exploring many perspectives and information sources may provide insight into how the organization works, what information is available, who the key players are and where there issues exist, to name a few. Not exploring may lead the roadmapping team to believe they understand the issues driving the need for the roadmaps or the perspectives of key stakeholders or that information is non-existent, only to later find out that their limited perspective was inaccurate. Using roadmapping as an explorative and iterative tool is necessary, especially during the early phases of the initiative.

8.1.5 Identify and engage the right people

The challenges and complexity of roadmapping require a champion who can create and communicate the vision for roadmapping, build the necessary support, drive the transformational change and lead the roadmapping initiative. The visionary must truly understand the benefits and limitations of roadmapping to be able to continuously adapt and evolve the process in order to realize the potential of roadmapping. This is especially true during the first exploratory roadmapping cycles, as the organization descends the learning curve and begins to understand roadmapping process.

Finding and involving the people who possess the necessary networks, attitudes, knowledge and willingness is important throughout entire roadmapping initiative. Roadmapping is a difficult task that requires broad and cross-functional participation. The people must possess the relevant knowledge and perspectives and because of the difficulty, they must also be willing to invest the effort to be a valuable contributor. These are also the type of people sought after by many other initiatives so obtaining their involvement may be difficult. It is also necessary.

8.1.6 Supply adequate resources and time to the participants

As with any large-scale improvement initiative, dedicate the resources necessary for success. The challenges of implementing roadmapping and the time-delay in realizing the benefits suggest that dedicating a cross-functional team to the initiative will improve the odds of success. Many process improvement initiatives fail because those responsible for the improvement do not have adequate time to devote to the initiative. When this is the case, their short-term responsibilities by which this performance is measured will always take precedence over the long-term improvement initiative. Select the right people, provide adequate resources and establish performance metrics for the initiative to show the importance and the leadership support for the initiative.

8.1.7 Coach and train the participants, patiently and persistently

There is a time-delay between the investment of time and effort and the realization of the benefits. Understanding and expecting this is important, as roadmapping requires every stakeholder and participant to learn about roadmapping, consider unfamiliar perspectives and synthesize large amounts of information. It is not uncommon for a participant to initially state that he understands and possesses the necessary information, only to later state that roadmapping is really difficult and he did not make much progress due to the complexity of the situation. Indeed, roadmapping is simple in concept and it is not until the first attempt that one realizes the challenge of roadmapping. Therefore, be patient and persistent in supporting the roadmapping participants and initiative, while also providing the coaching and training necessary to provide the participants the knowledge and skills necessary for roadmapping.

8.1.8 Adapt and evolve the process and the roadmaps

As with any complex system or process, it is important to understand that it will never be designed perfect the first time around. This is also true with roadmapping and even if the perfect roadmapping process was designed and executed, the capabilities and knowledge gained from the last roadmap cycle can be leveraged to evolve roadmapping to do more with less. Since it is unlikely that anyone attempting roadmapping will implement it perfectly the first time around, it is important for everyone involved to adapt and evolve to fit the current environment in which roadmapping is taking place. Some people will stop participating, some information will never be obtained and some things will simply not work, but these failures should be viewed as lessons learned to continuously improve the process.

8.2 Final Comments

Following the process described in this thesis, manufacturing technology roadmapping has been successfully implemented and Raytheon SAS has communicated their commitment to roadmapping as a useful tool for the strategic management of technology. As Raytheon SAS continues to improve its understanding of roadmapping, and as the communication channels and cross-functional linkages are strengthened, they will discover that level of effort required for roadmapping will improve. This will pave the way for Raytheon to evolve and expand roadmapping into an even more effective and powerful technology management tool.

The use of technology roadmapping as a tool for developing and deploying an integrated technology strategy within corporations around the world is becoming more common, as organizations realize its potential benefits. While this thesis discusses the development and implementation of a roadmapping process for Raytheon SAS's manufacturing technologies ("indirectly-valued" technologies), the author believes the distinction between "directly-valued" and "indirectly-valued" capabilities has important implications for strategic planning, business practices, cross-functional communication and investment decision-making, in addition to technology roadmapping.

This project focused on the initiation and roadmap development phases of the roadmapping initiative at Raytheon SAS. Louis Grillon will continue the project, building off the lessons learned from this project to continue the roadmap development phase and begin the integration phase.

Appendix A DoD Acquisition System

DoD acquisition system is depicted below from a 2006 DoD report. Here we see that "Big "A"" is the total acquisition process encompassing; requirements, budget, and acquisition. It is known as a system of systems. Each one of these is run semi- independently of the other.

1. The Joint Capabilities Integration and Development System (JCIDS) – the requirements system
2. The Planning, Programming, Budgeting, and Execution System (PPBE) – the budgeting system
3. The Defense Acquisition System (DAS) – the acquisition system

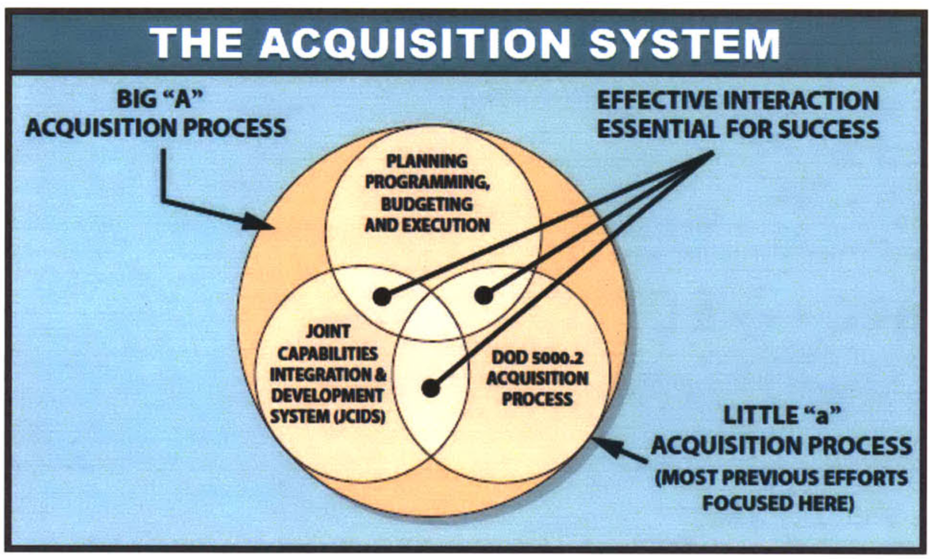

Figure 18: The Acquisition System (Kadish, 2006)

These different interdependent systems will be elaborated in the following sections. It is important to remember that they all interact with each other, so a change to one will impact the others, and the entire DoD acquisition process as a whole.

The Joint Capabilities Integration and Development System (JCIDS)

JCIDS is the process by which DOD identifies, assesses, and prioritizes what capabilities the military requires to fulfill its mission. (Schwartz, 2010) This is a capability based approach as opposed to the older threats based approach. The JCIDS will identify the capability that the warfighter needs. For a solution to be approved it must meet the following requirements.

1. Capabilities required to perform the defined mission
2. Gap in capabilities required to perform the mission
3. Need to address the capability gap.

Once approved the program enters the Defense Acquisition System (DAS). (Schwartz, 2010)

The Planning, Programming, Budgeting, and Execution System (PPBE)

According to DoD, the PPBE is intended to manage DoD resources effectively for successful mission accomplishment consistent with national resource limitations; the PPBE develops DoD's proposed budget for all acquisitions. (Taft, 1984) This budgeting process is broken down into four stages; planning, programming, budgeting, and execution. The objective of the planning stage is to identify the needs of the combatant commands. This guides the DoD efforts to propose acquisition programs. The programming stage is next. This consists of elaborating on selected programs so that there are sufficient details. These programs are then submitted in the Program Objective Memorandum (POM). During the programming phase the budgeting phase is happening at the same time. This phase involves the budgeting for programs. The execution stage is the last one, during this time programs are evaluated on their ability to execute. This process runs on a year cycle, where planning and programming occur every other year and budgeting and execution occur each year. (Schwartz, 2010)

The Defense Acquisition System (DAS)

The Defense Acquisition System (DAS) is quoted as the following excerpt from DoD directive 5000.1.

"The Defense Acquisition System exists to manage the nation's investments in technologies, programs, and product support necessary to achieve the National Security Strategy and support the United States Armed Forces. " "The primary objective of Defense acquisition is to acquire quality products that satisfy user needs with measurable improvements to mission capability and operational support, in a timely manner, and at a fair and reasonable price." (Paul Wolfowitz , 2003)

The operation of DAS is explained in directive 5000.2. The various programs are managed by a program manager. The primary tool used to manage and track the programs is milestones. For a program to enter the DAS it must be authorized. To receive authorization a program must meet all the criteria for entering into the milestone phase they are entering and pass through a Materiel Development Decision (MDD) review. The various milestones are detailed in the following graphic. (DoD, 2008)

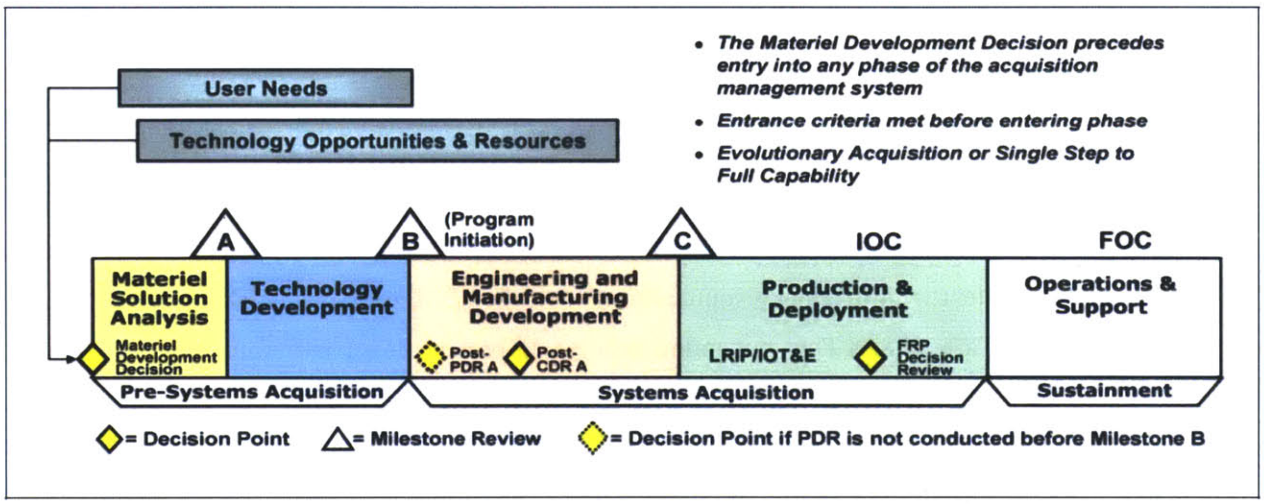

Figure 19: DoD Milestones and Phases

Before going into detail of the DAS and various phases and milestones it is important to note that the three systems; JCIDS, PPBE, and DAS each have their own objectives that are not always perfectly aligned. This causes many different organizational values to be displayed within the process as a whole. These values pull in different directions causing instability. The instability of the system itself is magnified by the ever-increasing changing environment that it has to react to.

The defense industry has greatly changed over the past 25 years. Threats used to be well-known and well-defined. This allowed for large production volumes of weapon systems, and thus a large contractor base of over 20 prime contractors. Now the security environment is unpredictable with difficult to define threats. This means that weapon systems need to be developed quicker to meet the current needs.

Production volumes have dropped by at least 2/3 and only six prime contractors remain. (Kadish, 2006) Now further elaboration will continue on the various phases and milestones of the DAS.

Material Solution Analysis

The major objective of the Material Solution Analysis phase is to determine what options exist to achieve the necessary requirements and to develop a technology development strategy. An Analysis of Alternatives (AoA) is conducted to determine the various options to meet the needs and which are best suited to do this in a cost effective manner with minimal risk. Once a material solution is recommended and the other requirements for milestone A are met, the program moves onto the Technology and Development Phase.

Milestone A

Milestone A requires that a program submit a cost estimate to complete the material solution that was the output of the AoA. The material solution and the technology development strategy must then be approved. Once this is complete the program moves into the Technology and Development Phase.

Technology and Development Phase

The Technology and Development Phase involves the program determining what specific technologies are required to develop the material solution that was generated from the Material Solution Analysis phase. The technologies are required to be demonstrated by prototyping and also to be affordable. Both the technology and the manufacturing process must be developed in a production relevant environment. In addition to an actual prototype, a Capability Development Document is created which details the operational performance parameters that the system is targeting to achieve. A Reliability, Availability, and Maintainability (RAM) strategy is also developed for the system as a whole. (David Duma and Kenneth Krieg, 2005) Once all this is completed the program has to pass Milestone B to enter the Engineering and Manufacturing Development phase.

Milestone B

Milestone B requires that the Acquisition Strategy, the Acquisition Program Baseline, and the type of contract that will be used to acquire the system are approved. (Schwartz, 2010) This is the milestone where most programs are formally initiated.

Engineering and Manufacturing Development

The Engineering and Manufacturing Development phase consists of two sub phases; Integrated System Design and System Capability & Manufacturing Processes Demonstration. During Integrated System Design the various sub systems are assembled into a complete system or prototype. For a program to move to the next sub phase it must pass a Post-preliminary Design Review (PDR) which makes sure the system meets the requirements. It must also pass a Post-Critical Design Review (CDR) Assessment which verifies that the system meets the required design maturity.

System Capability & Manufacturing Processes Demonstration involves various testing of the system to make sure that it can provide military usefulness. It is also verified that the system can be supported through the manufacturing process at this stage. For the system to complete the Engineering and Manufacturing Development phase and move onto Production and Deployment phase it must pass Milestone C, meet performance requirements as demonstrated by a production-representative article in an intended environment, and show that the manufacturing processes work and can produce the intended system.

Milestone C

To pass Milestone C a program must meet the following; passed developmental testing and operational assessment, demonstrated interoperability and operational supportability, demonstrated affordability, and be fully funded. (Schwartz, 2010) Once it has passed Milestone C a program begins low-rate initial production (LRIP).

Production and Deployment

LRIP is the initial stage of the Production and Deployment phase. Here manufacturing and quality can prepare for higher rate production. Parts from this phase go through operational test and evaluation (OT&E). Once testing is completed and the necessary control over the manufacturing process is demonstrated, the approval for full rate production can be given. The last phase is Operations and Support. Here the program supports the systems in the field.

Appendix B DoD Manufacturing Readiness Level Definitions

This entire section is taken directly from the following source. (Gordon, Manufacturing Readiness Levels)

MANUFACTURING READINESS LEVEL DEFINITIONS

There are ten MRLs (numbered 1 through 10) that are correlated to the nine TRLs in use. The final level (MRL 10) measures aspects of lean practices and continuous improvement for systems in production.

MRL 1: Basic Manufacturing Implications Identified

This is the lowest level of manufacturing readiness. The focus is to address manufacturing shortfalls and opportunities needed to achieve program objectives. Basic research (i.e., funded by budget activity) begins in the form of studies.

MRL 2: Manufacturing Concepts Identified

This level is characterized by describing the application of new manufacturing concepts. Applied research (i.e., funded by budget activity 6.2) translates basic research into solutions for broadly defined military needs. Typically this level of readiness in the S&T environment includes identification, paper studies and analysis of material and process approaches. An understanding of manufacturing feasibility and risk is emerging.

MRL 3: Manufacturing Proof of Concept Developed

This level begins the validation of the manufacturing concepts through analytical or laboratory experiments. This level of readiness is typical of technologies in the S&T funding categories of Applied Research and Advanced Development (i.e., funded by budget activity 6.3). Materials and/or processes have been characterized for manufacturability and availability but further evaluation and demonstration is required. Experimental hardware models have been developed in a laboratory environment that may possess limited functionality.

MRL 4: Capability to produce the technology in a laboratory environment

This level of readiness is typical for S&T Programs in the budget activity 6.2 and 6.3 categories and acts as an exit criterion for the Materiel Solution Analysis (MSA) Phase approaching a Milestone A decision. Technologies should have matured to at least TRL 4. This level indicates that the technologies are ready for the Technology Development Phase of acquisition. At this point, required investments, such as manufacturing technology development, have been identified. Processes to ensure manufacturability, producibility, and quality are in place and are sufficient to produce technology demonstrators. Manufacturing risks have been identified for building prototypes and mitigation plans are in place. Target cost objectives have been established and manufacturing cost drivers have been identified. Producibility assessments of design concepts have been completed. Key design performance parameters have been identified as well as any special tooling, facilities, material handling and skills required.

MRL 5: Capability to produce prototype components in a production relevant environment

This level of maturity is typical of the mid-point in the Technology Development Phase of acquisition, or in the case of key technologies, near the mid-point of an Advanced Technology Demonstration (ATD) project. Technologies should have matured to at least TRL 5. The industrial base has been assessed to identify potential manufacturing sources. A manufacturing strategy has been refined and integrated with the risk management plan. Identification of enabling/critical technologies and components is complete. Prototype materials, tooling and test equipment, as well as personnel skills have been demonstrated on components in a production relevant environment, but many manufacturing processes and procedures are still in development. Manufacturing technology development efforts have been initiated or are ongoing. Producibility assessments of key technologies and components are ongoing. A cost model has been constructed to assess projected manufacturing cost.

MRL 6: Capability to produce a prototype system or subsystem in a production relevant environment

This MRL is associated with readiness for a Milestone B decision to initiate an acquisition program by entering into the Engineering and Manufacturing Development (EMD) Phase of acquisition. Technologies should have matured to at least TRL 6. It is normally seen as the level of manufacturing readiness that denotes completion of S&T development and acceptance into a preliminary system design. An initial manufacturing approach has been developed. The majority of manufacturing processes have been defined and characterized, but there are still significant engineering and/or design changes in the system itself. However, preliminary design of critical components has been completed and producibility assessments of key technologies are complete. Prototype materials, tooling and test equipment, as well as personnel skills have been demonstrated on systems and/or subsystems in a production relevant environment. A cost analysis has been performed to assess projected manufacturing cost versus target cost objectives and the program has in place appropriate risk reduction to achieve cost requirements or establish a new baseline. This analysis should include design trades. Producibility considerations have shaped system development plans. The Industrial Capabilities Assessment (ICA) for Milestone B has been completed. Long-lead and key supply chain elements have been identified.

MRL 7: Capability to produce systems, subsystems, or components in a production representative environment

This level of manufacturing readiness is typical for the mid-point of the Engineering and Manufacturing Development (EMD) Phase leading to the Post-CDR Assessment. Technologies should be on a path to achieve TRL 7. System detailed design activity is underway. Material specifications have been approved and materials are available to meet the planned pilot line build schedule. Manufacturing processes and procedures have been demonstrated in a production representative environment. Detailed producibility trade studies and risk assessments are underway. The cost model has been updated with detailed designs, rolled up to system level, and tracked against allocated targets. Unit cost reduction efforts have been prioritized and are underway. The supply chain and supplier quality assurance have been assessed and long-lead procurement plans are in place. Production tooling and test equipment design and development have been initiated.

MRL 8: Pilot line capability demonstrated; Ready to begin Low Rate Initial Production

This level is associated with readiness for a Milestone C decision, and entry into Low Rate Initial Production (LRIP). Technologies should have matured to at least TRL 7. Detailed system design is essentially complete and sufficiently stable to enter low rate production. All materials are available to meet the planned low rate production schedule. Manufacturing and quality processes and procedures have been proven in a pilot line environment and are under control and ready for low rate production. Known producibility risks pose no significant challenges for low rate production. The engineering cost model is driven by detailed design and has been validated with actual data. The Industrial Capabilities Assessment for Milestone C has been completed and shows that the supply chain is established and stable.

MRL 9: Low rate production demonstrated; Capability in place to begin Full Rate Production

At this level, the system, component or item has been previously produced, is in production, or has successfully achieved low rate initial production. Technologies should have matured to TRL 9. This level of readiness is normally associated with readiness for entry into Full Rate Production (FRP). All systems engineering/design requirements should have been met such that there are minimal system changes.

Major system design features are stable and have been proven in test and evaluation. Materials are available to meet planned rate production schedules. Manufacturing process capability in a low rate production environment is at an appropriate quality level to meet design key characteristic tolerances. Production risk monitoring is ongoing. LRIP cost targets have been met, and learning curves have been analyzed with actual data. The cost model has been developed for FRP environment and reflects the impact of continuous improvement.

MRL 10: Full Rate Production demonstrated and lean production practices in place

This is the highest level of production readiness. Technologies should have matured to TRL 9. This level of manufacturing is normally associated with the Production or Sustainment phases of the acquisition life cycle. Engineering/design changes are few and generally limited to quality and cost improvements. System, components or items are in full rate production and meet all engineering, performance, quality and reliability requirements. Manufacturing process capability is at the appropriate quality level. All materials, tooling, inspection and test equipment, facilities and manpower are in place and have met full rate production requirements. Rate production unit costs meet goals, and funding is sufficient for production at required rates. Lean practices are well established and continuous process improvements are ongoing. Although the MRLs are numbered, the numbers themselves are unimportant. The numbers represent a non-linear ordinal scale that identifies what maturity should be as a function of where a program is in the acquisition life cycle (as described in Section 3). Using numbers is simply a convenient naming convention.

Appendix C SAS Mission Areas

Tactical Airborne Systems (TAS) (Raytheon, 2011)

Tactical Airborne Systems is a world-leading provider of sensors and systems integration expertise, offering superior technologies such as advanced fire control radars, avionics, electronic warfare systems and processor technologies. Our products deliver enhanced capabilities and performance for both manned and unmanned platforms across all operational mediums: air, land, sea, space, and cyberspace. Our mission is to provide integrated air dominance solutions, resulting in actionable information and mission assurance for the warfighters of today and the future.

Key TAS Capabilities:

- Advanced Fire Control Radars
- Electronic Warfare Systems
- Airborne Processors and Avionics

Intelligence, Surveillance & Reconnaissance (ISR) (Raytheon, 2011)

Providing the joint warfighter with actionable information from an unblinking eye across the battle space.

- Air-to-ground and Maritime Surveillance Systems
- Active and Passive Electronically Scanned Array Radars
- Electro-Optical/Infrared Sensors
- Integrated Sensor Suites
- Multi-Platform Integrated Mission Solutions
- Performance Based Logistics and Lifecycle Mission Support

Space Systems (SS) (Raytheon, 2011)

- Leading the industry in space-enabled information solutions.
- Intelligence Gathering and Ground Surveillance
- Earth Observation and Climate Monitoring

- Advanced Missile Warning
- Space Protection
- Rapidly Deployable Payload Technologies

Raytheon Applied Signal Technology (AST) (Applied Signal Technology, Inc. , 2011)

We provide expertise in the areas of broadband communications, signals intelligence, cyber security, and sensor surveillance, with a common core competency in digital signal processing. SIGINT capabilities include the collection and exploitation of communication signals and the interception of electromagnetic signals, such as radar and weapons systems, for electronic intelligence. Cyber security capabilities include network monitoring, intrusion detection, and countermeasures. Remote sensing capabilities include processing information from sonar, radar, magnetic, electromagnetic, infrared, electro-optical, hyperspectral, and visible light sensors to detect abnormalities of interest and increase situational awareness. We have experience in space, airborne, terrestrial, and undersea environments.

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